**Naval Research Laboratory**

Washington, DC 20375-5320

NRL/MR/6120--00-8483

# Conductivity and Charging Tendency of JP-8 + 100 Jet Fuel

J.T. LEONARD

*Geo-Centers, Inc.*
*Newton, MA*

D.R. HARDY

*Materials Chemistry Branch*
*Chemistry Division*

September 18, 2000

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY (*Leave Blank*) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | September 18, 2000 | Final |

4. TITLE AND SUBTITLE

Conductivity and Charging Tendency of JP-8 + 100 Jet Fuel

5. FUNDING NUMBERS

6. AUTHOR(S)

J.T. Leonard* and D.R. Hardy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6120--00-8483

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Department of the Air Force
Wright Laboratory
AeroPropulsion and Power Directorate
Wright-Patterson Air Force Base, OH 45433-7103

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Geo-Centers, Inc.
Newton, MA 02459

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The effects of the Betz Thermal Stability Additive, 8Q492, and the Octel Static Dissipater Additive, Stadis 450, on the electrical conductivity and electrostatic charging tendency of Jet A fuels were examined using a variety of filter media. It was found that the Betz additive, at a concentration of 256 mg/l, increased the conductivity of most fuels to above 100 pS/m and of 15% of the fuels to above 150 pS/m, which is the lower specification limit for JP-8 fuels. The Betz additive increased the charging tendency to very high levels on only two media, namely, the Type 10 reference filter and a coalescer medium. Charging on all other media including both the non-conductive and conductive reticulated foams was quite low.

Fuels containing Stadis 450 exhibited high charging on most coalescer media, particularly fiberglass and felt, and on the media paper and superabsorbent and absorbent media from the monitor cartridge. They also gave high charging on both the conductive and nonconductive foams, but not on the separator media or on the Type 10 reference filter.

14. SUBJECT TERMS

Jet fuel — Electrical conductivity
JP-8
Electrostatic charging

15. NUMBER OF PAGES

53

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

**CONDUCTIVITY AND CHARGING TENDENCY OF JP-8+ 100 JET FUEL**

## INTRODUCTION

The Air Force has recently developed a new additive package for JP-8 to produce "JP-8 + 100" jet fuel. In addition to improving the thermal stability of JP-8 fuel, the new additives also increase the electrical conductivity of the fuel. Since additives which increase the conductivity of fuel also increase its electrostatic charging tendency, this development has prompted the following questions:

1) Is the electrical conductivity of JP-8 +100 sufficiently high to obviate the need for the current static dissipater additive (SDA)?

2) Are there any unusual electrostatic charging characteristics associated with JP-8 +100 fuels?

The objective of this study is to provide answers to the questions above.

## EXPERIMENTAL PROCEDURE

Forty-eight samples of Jet A fuels were provided by the Air Force Research Laboratory. Unless otherwise indicated, all of these samples contained:

1) A Corrosion Inhibitor (CI), Betz 8QM21, at 15 mg/l and

2) A Fuel System Icing Inhibitor (FSII), Diethyleneglycol monomethyl ether, at 0.1 vol. %.

Most of the samples also contained the Betz Thermal Stability Additive 8Q492 at a concentration of 256 mg/l. However, the Betz additive was omitted from certain samples for a baseline comparison. The Octel Static Dissipater Additive, Stadis 450 Enhanced, was used at a concentration of 1 ppm unless otherwise indicated.

The electrical conductivity of the fuel samples was measured using an Emcee Electronics, Inc. Precision Conductivity Meter, Model 1154 and the ASTM procedure (1). The charging tendency was determined using the EXXON Mini-Static Test Apparatus and Procedure (2). For the first phase of testing, Type 10 separator paper was used in the Mini-Static apparatus (Fig. 1). Type 10 paper was chosen because it was used previously in the CRC survey of fuels taken from commercial airports and military bases in the continental United States and Hawaii (3). A total of 410 samples, representing 338 commercial Jet A and Jet A-1 fuels, 54 JP-4 and 18 JP-5 fuels, were included in that survey. In addition, Type 10 paper was used to evaluate the charging tendency of a wide range of organic compounds, fuel additives and contaminants in a

Manuscript approved August 3,

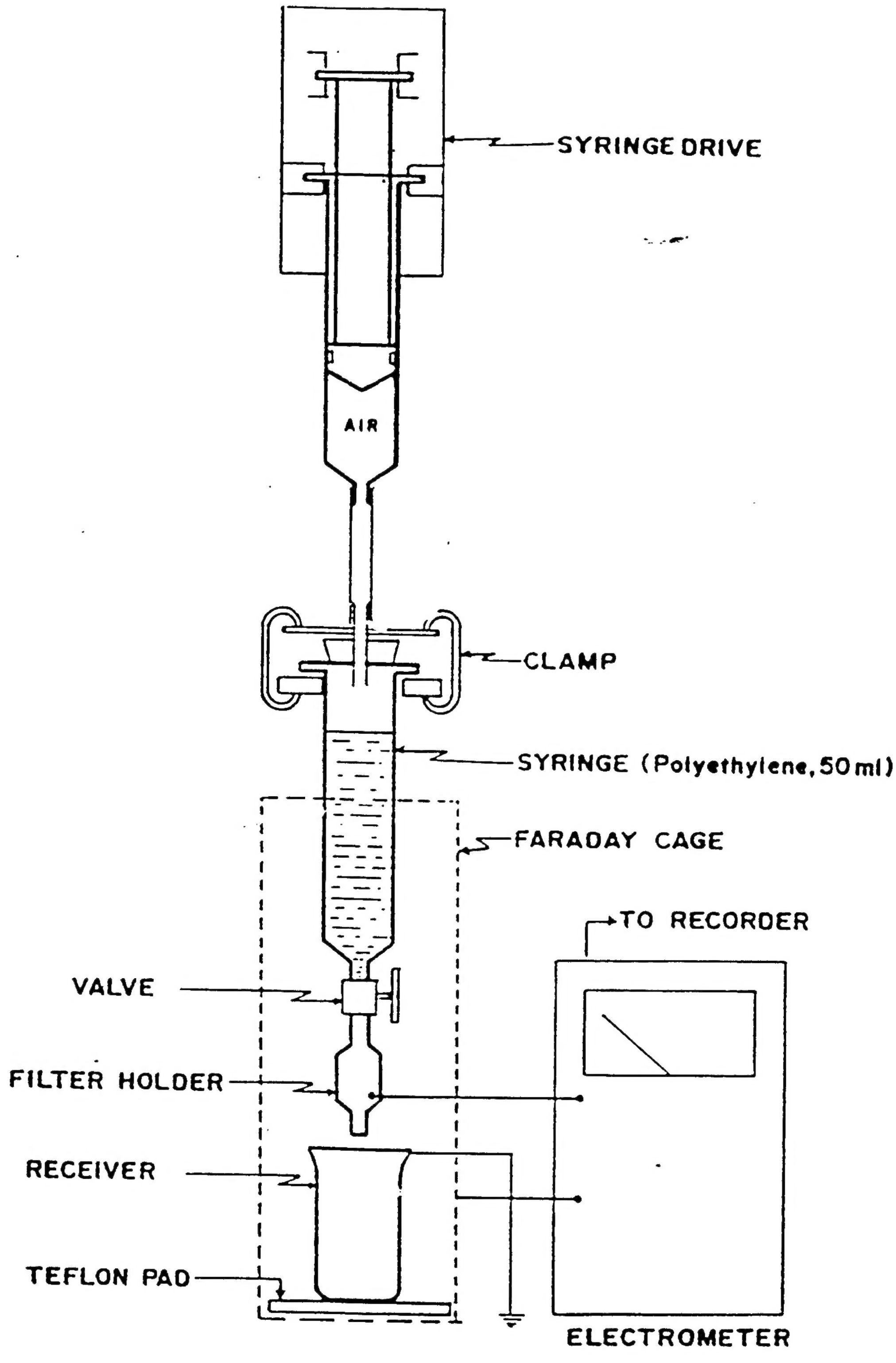



Fig. 1-EXXON Mini-Static Tester

later study (4). Hence, there is an abundance of data available on fuel charging with this particular paper.

Following the initial fuel conductivity and charging tendency measurements, the fuel samples were doped with 1 ppm Stadis 450 Enhanced (the currently approved static dissipater additive for JP-8 fuels) and the conductivity and charging tendency of the treated samples were measured.

In the second phase of the study, the charging tendencies of the highest charging JP-8 + 100 fuels were measured using a variety of filter media in place of the Type 10 paper in the EXXON Mini-Static Test Apparatus. The filter media were supplied by three manufacturers, namely: Facet International, Pall Corporation and Velcon Filters. The filters were representative of the media used in coalescers, separators and monitor cartridges. In addition, an experimental coalescer material was also tested. The filters were cut to fit the filter holder on the Mini-Static Test Apparatus using a 1.3 cm arch leather punch.

Finally, the charging tendencies of fuels containing the Betz Thermal Stability Additive were compared with the charging tendencies of the same fuels containing Stadis 450 using reticulated foam as the charging medium. For these tests, the filter holder was enlarged to accommodate a cylindrical section of foam (1.3 cm in diameter, 7.5 cm long), as was done in a previous study of reticulated foams (5).

## RESULTS AND DISCUSSION

Typical filter current curves as obtained from the EXXON Mini-Static Tester are shown in Fig. 2. The vast majority of fuel samples produced curves like this after one or two passes through the filter. However, a few samples showed progressively increasing or decreasing filter currents and hence, could not be adequately measured by this technique. The filter currents were divided by the volumetric flow rate to express fuel charging tendency in microcoulombs per cubic meter ($\mu C/m^3$).

### Conductivity of Fuels as Received

The conductivities of the fuel samples which did not contain the Betz additive are shown in Table 1 and in Fig. 3. Conductivity is expressed as picosiemens per meter (pS/m).

As indicated in Table 1, the conductivity of the neat fuel (Sample 1) was quite low (0.15 pS/m), but comparable to the lowest value (0.09 pS/m) found in a survey of Jet A fuels in 1975 (3). The addition of a Fuel System Icing Inhibitor (FSII) and Corrosion Inhibitor (CI) to this fuel (Sample 2) increased the conductivity only slightly (to 0.22 pS/m).

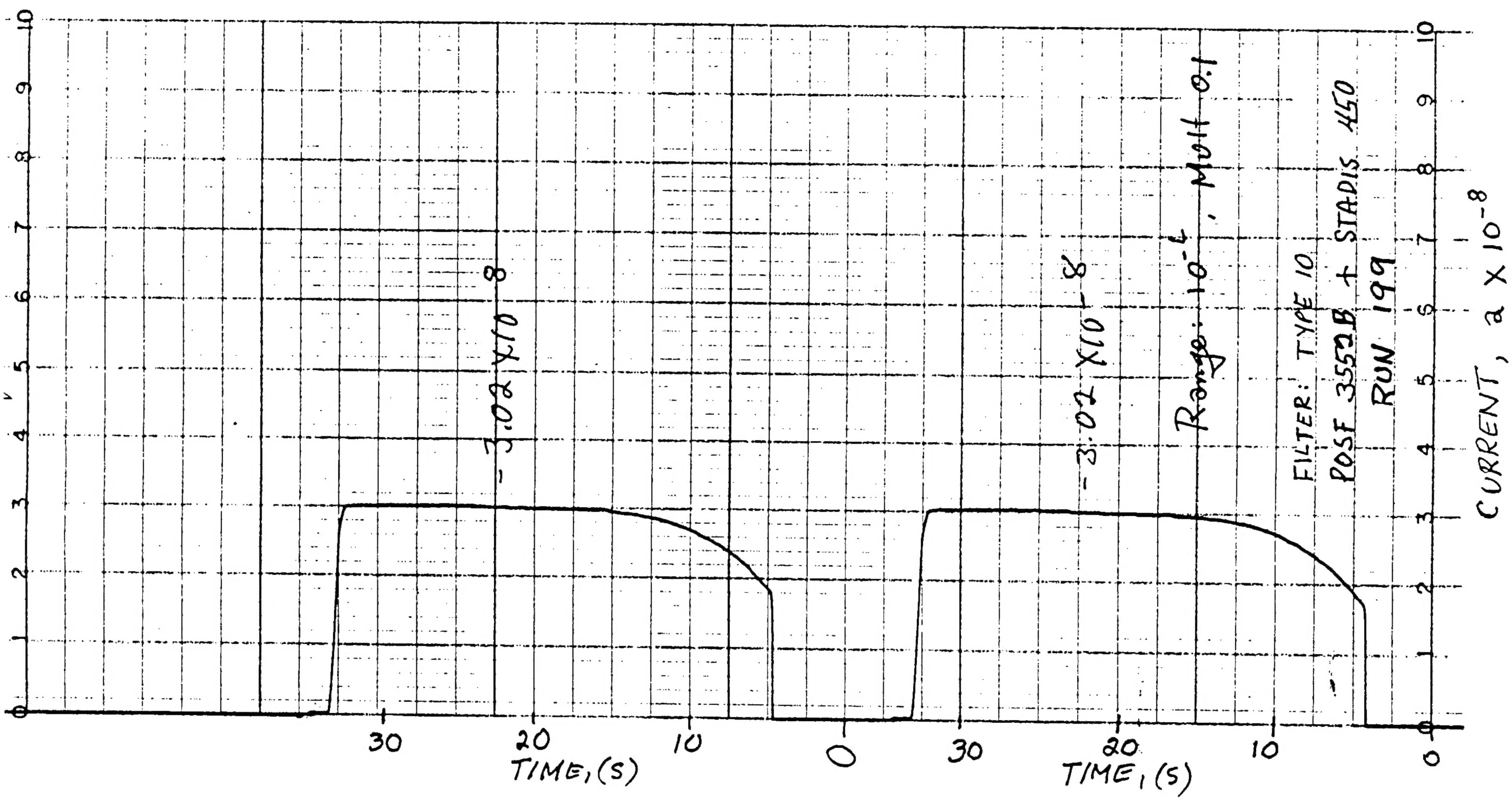



Fig. 2-Typical Filter Current Curves for Two Successive Passes of Fuel Sample Through a Type 10 Filter

Fig. 3- Conductivity of Fuels Not Containing Betz Additive

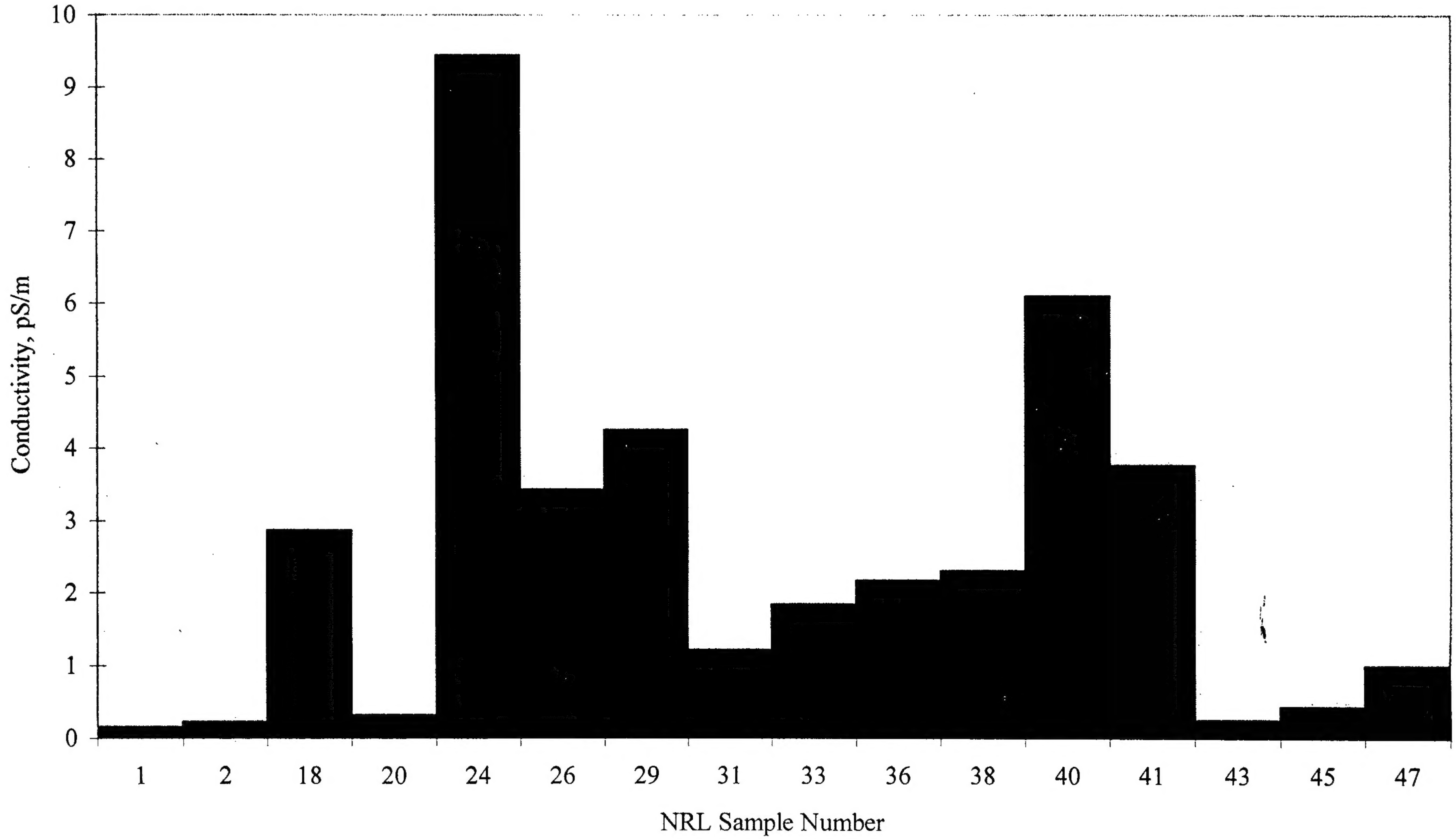


**Table 1 – Conductivity and Charging Tendency of Fuel Samples Not Containing Betz Additive (Filter: Type 10 Paper)**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Charge Density, μC/m³ |
|---|---|---|---|
| **A. Samples in Normal Jet A Conductivity Range** | | | |
| 1 | 3428 (Neat)* | 0.15 | 28 |
| 2 | 3428 | 0.22 | 480 |
| 18 | 3551A | 2.86 | 1,120 |
| 20 | 3552A | 0.31 | 231 |
| 24 | 3554A | 9.44 | 1,080 |
| 26 | 3555A | 3.43 | 1,890 |
| 29 | | 4.25 | 392 |
| 31 | 3627B | 1.22 | 397 |
| 33 | 3633B | 1.84 | 171 |
| 36 | 3638B | 2.17 | 634 |
| 38 | 3639B | 2.30 | 528 |
| 40 | 3640B | 6.10 | 488 |
| 41 | 3593A | 3.76 | 702 |
| 43 | 3601A | 0.25 | 131 |
| 45 | 3602A | 0.43 | 519 |
| 47 | 3603A | 1.00 | 610 |
| **B. High Conductivity Samples** | | | |
| 16 | 3550A | 79** | >180 |
| 22 | 3553A | 322** | 5,950 |

* This sample did not contain FSII or CI

** High conductivity indicates that sample may have contained Stadis 450

With the exception of two Samples (Samples 16 and 22), which apparently contained a static dissipater additive, the conductivities of all of the other samples were within the "normal range" for Jet A fuel not containing the Betz additive, i.e., below 10 pS/m. (In the 1975 survey (3), 93% of the Jet A and Jet A-1 fuels had conductivities below 10 pS/m.) By contrast, the conductivities of all of the samples containing the Betz additive (Table 2 and Fig. 4) were over 50 pS/m, which is the specification lower limit for Jet A fuels (6). Thirteen had conductivities above 150 pS/m, the specification lower limit for JP-8 fuels (7). Eight of the samples in Table 2, namely, Samples 8, 10, 12, 13, 14, 15, 17 and 23, had such high conductivities as to suggest that they contained both Betz and Stadis additives.

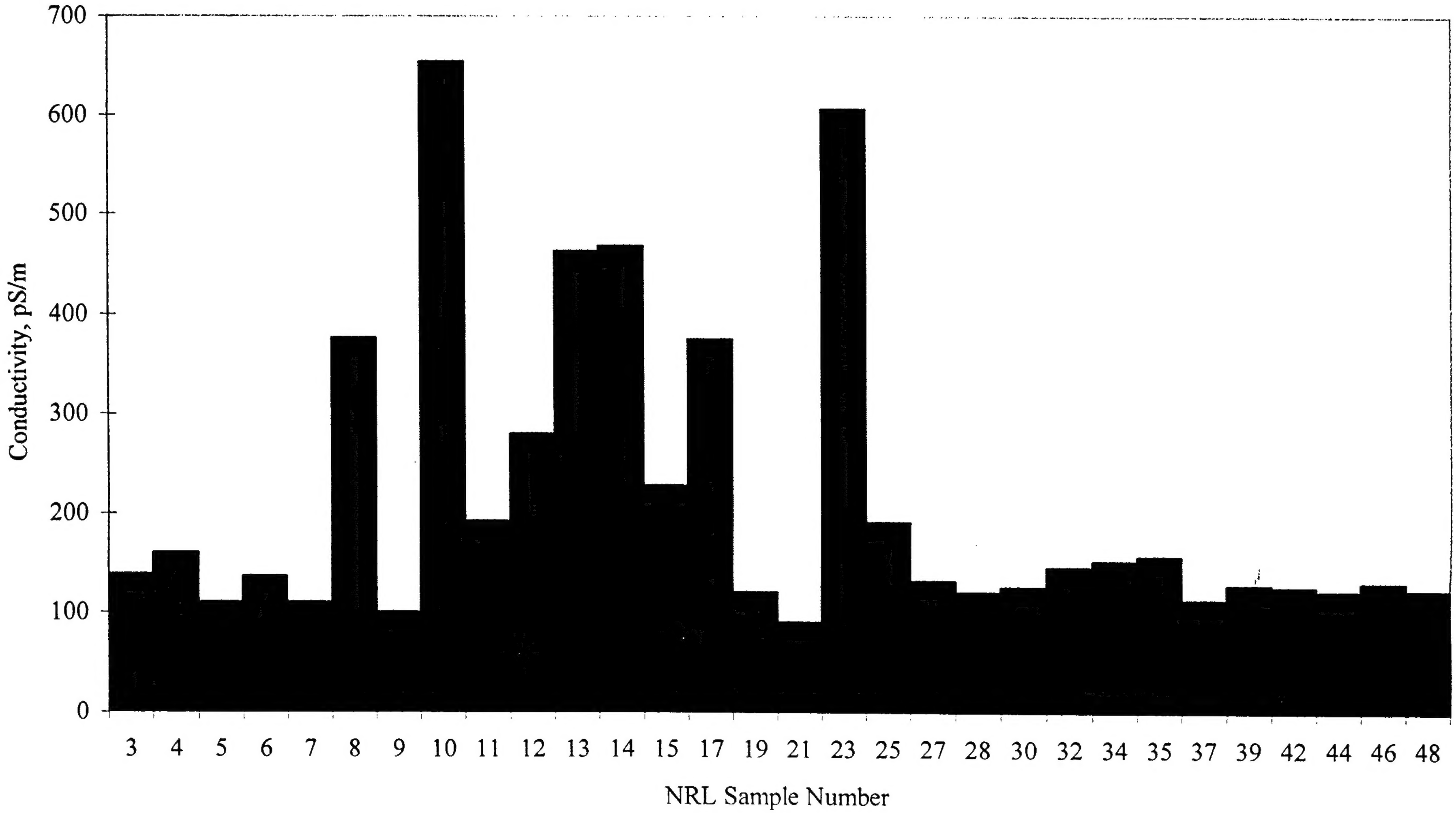
**Table 2 – Conductivity and Charging Tendency of Fuel Samples Containing Betz Additive (Filter: Type 10 Paper)**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Charge Density, μC/m$^3$ |
|---|---|---|---|
| **A. Samples in Normal Conductivity Range for Betz Additive** | | | |
| 3 | 2827 | 138 | 11,500 |
| 4 | 2926 | 160 | 15,300 |
| 5 | 3055 | 110 | 14,500 |
| 6 | 3119 | 136 | 14,400 |
| 7 | 3166 | 110 | 13,600 |
| 9 | 3084 | 100 | 15,500 |
| 11 | 3476 | 192 | 23,900 |
| 19 | 3551B | 121 | 3,210 |
| 21 | 3552B | 90.5 | 7,810 |
| 25 | 3554B | 191 | 2,490 |
| 27 | 3555B | 132 | 1,452 |
| 28 | 3166** | 121 | 10,980 |
| 30 | 3627A | 126 | 7,110 |
| 32 | 3633A | 146 | 3,360 |
| 34 | 3638 | 152 | 9,520 |
| 35 | 3638A | 157 | 5,490 |
| 37 | 3639A | 113 | 3,730 |
| 39 | 3640A | 128 | 12,400 |
| 42 | 3593B | 126 | 4,720 |
| 44 | 3601B | 122 | 9,060 |
| 46 | 3602B | 130 | 12,200 |
| 48 | 3603B | 123 | 5,190 |
| **B. High Conductivity Samples** | | | |
| 8 | 3219 | 376* | 17,700 |
| 10 | 3475 | 654* | 19,300 |
| 12 | 3477 | 280* | 26,100 |
| 13 | 3478 | 463* | 26,000 |
| 14 | 3479 | 468* | 22,000 |
| 15 | 3480 | 228* | 22,600 |
| 17 | 3550B | 375* | 12,000 |
| 23 | 3553B | 606* | 13,800 |

* High conductivity indicates that sample may have contained Stadis 450, although it was not labeled as such

** Second sample

Fig. 4- Conductivty of All Fuels Containing the Betz Additive



The effect of the Betz additive on the conductivities of "normal" Jet A fuels (i.e. fuels having a conductivity <10 pS/m) is seen more clearly in Table 3. This table lists only those samples which were received with and without the Betz additive. For these fuels, the Betz additive increased the conductivity an average of 129 pS/m. All but one sample (92%) had conductivities above 100 pS/m, but only 2 out of 13 samples (15%) were above 150 pS/m.

**Table 3 – Effect of Betz Additive on Conductivity and Charging Tendency of "Normal" Jet A Fuels (Filter: Type 10 Paper)**

| | | Conductivity, pS/m | | | Charge Density, μC/m$^3$ | | |
|---|---|---|---|---|---|---|---|
| NRL* Sample No. | AF* POSF No. | No Betz | With Betz | Δ | No Betz | With Betz | Δ |
| 18 &19 | 3551A&B | 2.86 | 121 | +118 | 1,120 | 3,210 | +2,090 |
| 20 & 21 | 3552A&B | 0.31 | 90.5 | +90.2 | 231 | 7,810 | +7,579 |
| 24 & 25 | 3554A&B | 9.44 | 191 | +182 | 1,080 | 2,490 | +1,410 |
| 26 & 27 | 3555A&B | 3.43 | 132 | +129 | 1,890 | 1,450 | -440 |
| 30 & 31 | 3627A&B | 1.22 | 126 | +125 | 397 | 7,110 | +6,713 |
| 32 & 33 | 3633A&B | 1.84 | 146 | +144 | 171 | 3,360 | +3,189 |
| 35 & 36 | 3638A&B | 2.17 | 157 | +155 | 634 | 5,490 | +4,856 |
| 37 & 38 | 3639A&B | 2.30 | 113 | +111 | 528 | 3,730 | +3,203 |
| 39 & 40 | 3640A&B | 6.10 | 128 | +122 | 488 | 12,400 | +11,912 |
| 41 & 42 | 3593A&B | 3.76 | 126 | +122 | 702 | 4,720 | +4,018 |
| 43 & 44 | 3601A&B | 0.25 | 122 | +122 | 131 | 9,060 | +9,029 |
| 45 & 46 | 3602A&B | 0.43 | 130 | +130 | 519 | 12,200 | +12,070 |
| 47 & 48 | 3603A&B | 1.00 | 123 | +123 | 610 | 5,190 | +4,580 |

* The dual sample numbers refer to the same sample, before and after the addition of the Betz additive

Although fuels vary in their response to the Betz additive as shown in Table 3, for a single fuel, the conductivity increases fairly linearly with concentration of Betz additive (Fig. 5).

In a previous study (4), it was found that the conductivities of Jet A fuels varied widely in response to corrosion inhibitors and other fuel additives when the fuels were doped at 100 and 1000 ppm levels. For example, all of the corrosion inhibitors increased the conductivity of Jet A fuel to some degree, but the most active corrosion inhibitor, Na-Sul LP, increased the conductivity of a Jet A fuel from 0.102 to 414 pS/m when used at the 1000 ppm level (Fig. 6). The thermal stability additive used in that study (JFA-5) had only a slight effect on fuel conductivity, raising it from 0.102 to 6.19 pS/m at the 1000 ppm level.

## Charging of Fuels on Type 10 Reference Filter

The charging tendencies for the samples that didn't contain the Betz additive were generally low (Table 1 and Fig. 7), but within the range found for Jet A samples in the 1975

Fig. 5- Effect of Betz Additive on Conductivity of Jet A Fuel (NRL Sample No. 34)

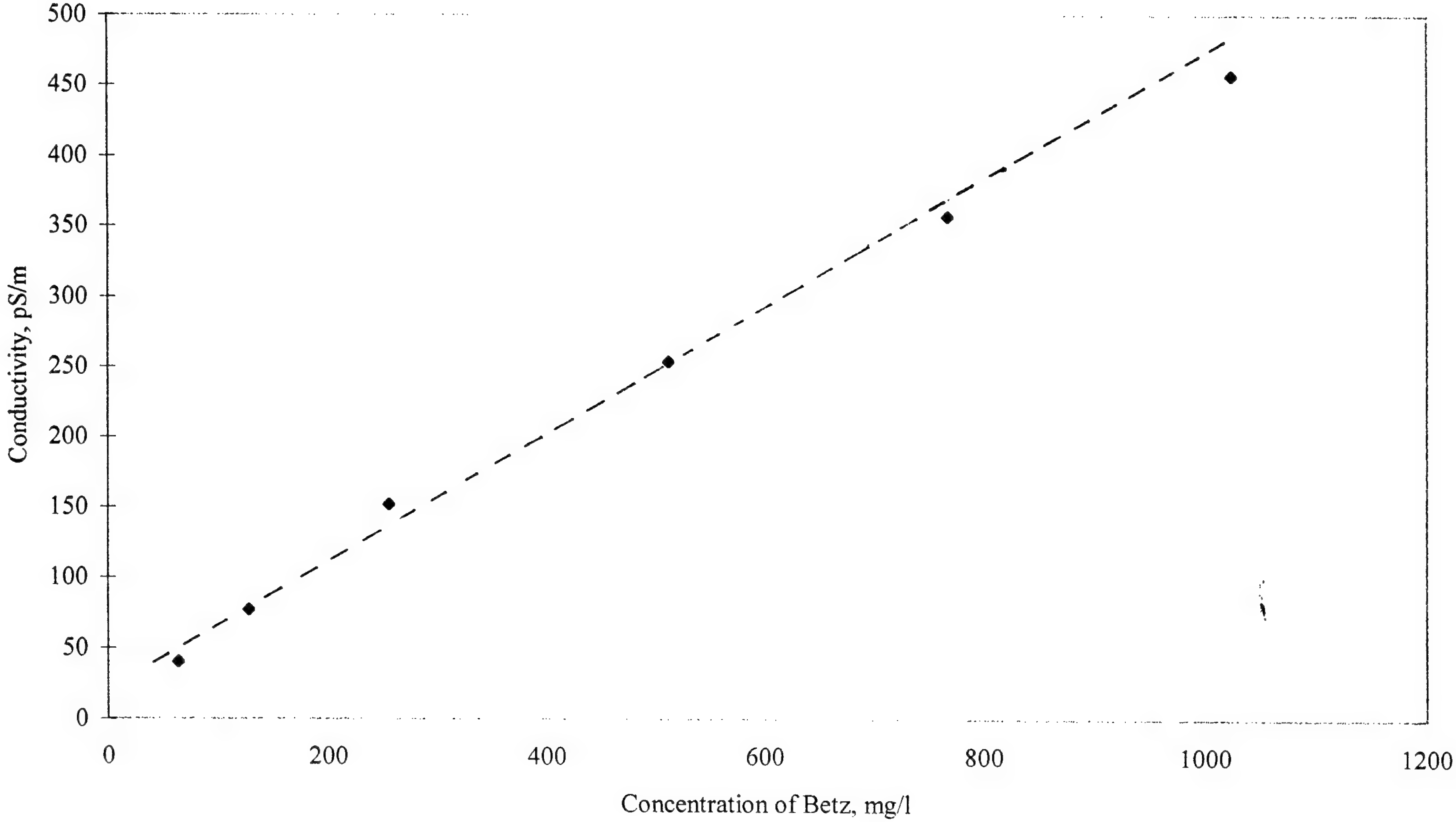


Fig. 6- Effect of Corrosion Inhibitors on Fuel Conductivity (Conductivity of Neat Fuel = 0.102 pS/m). Ref. 4

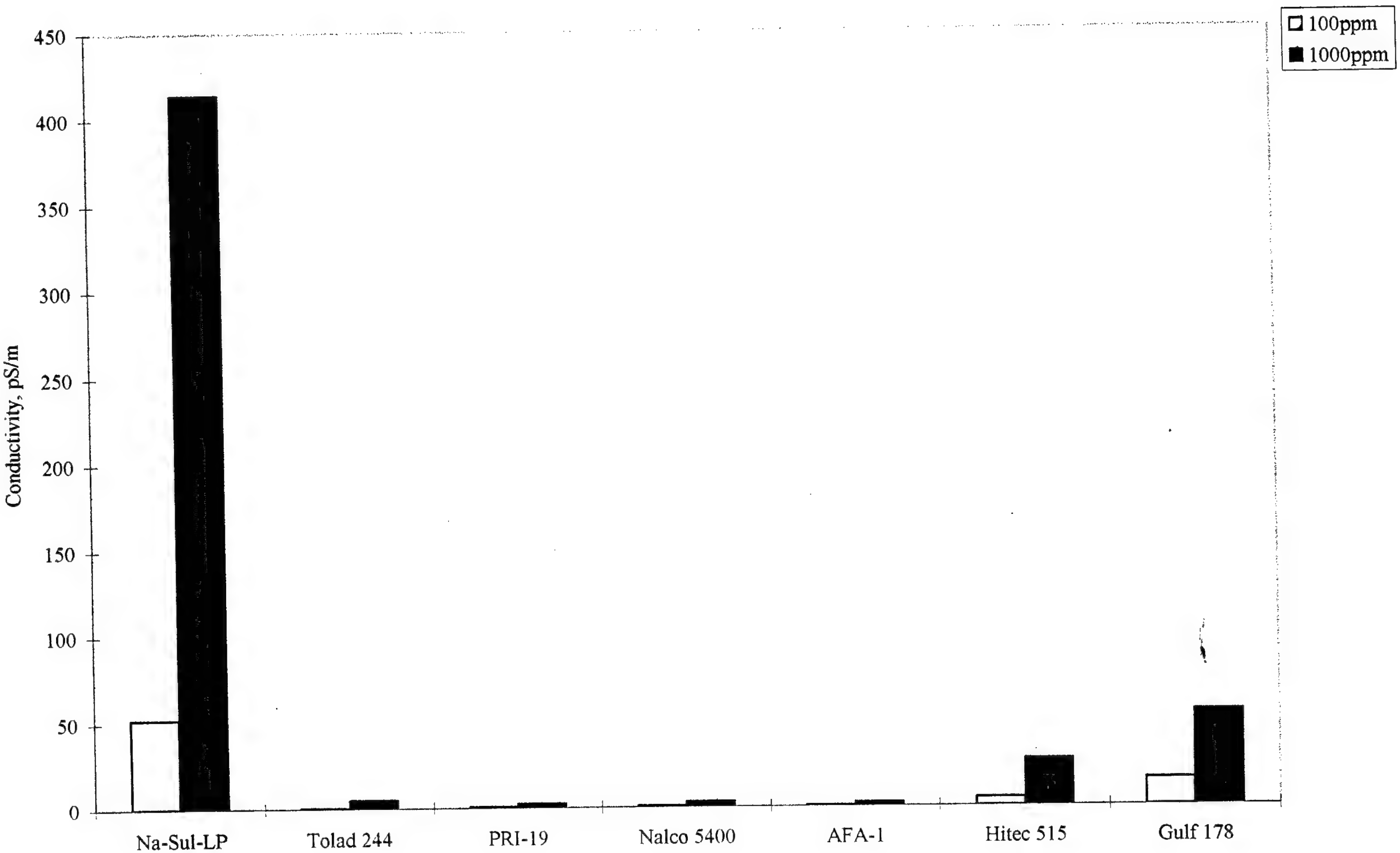
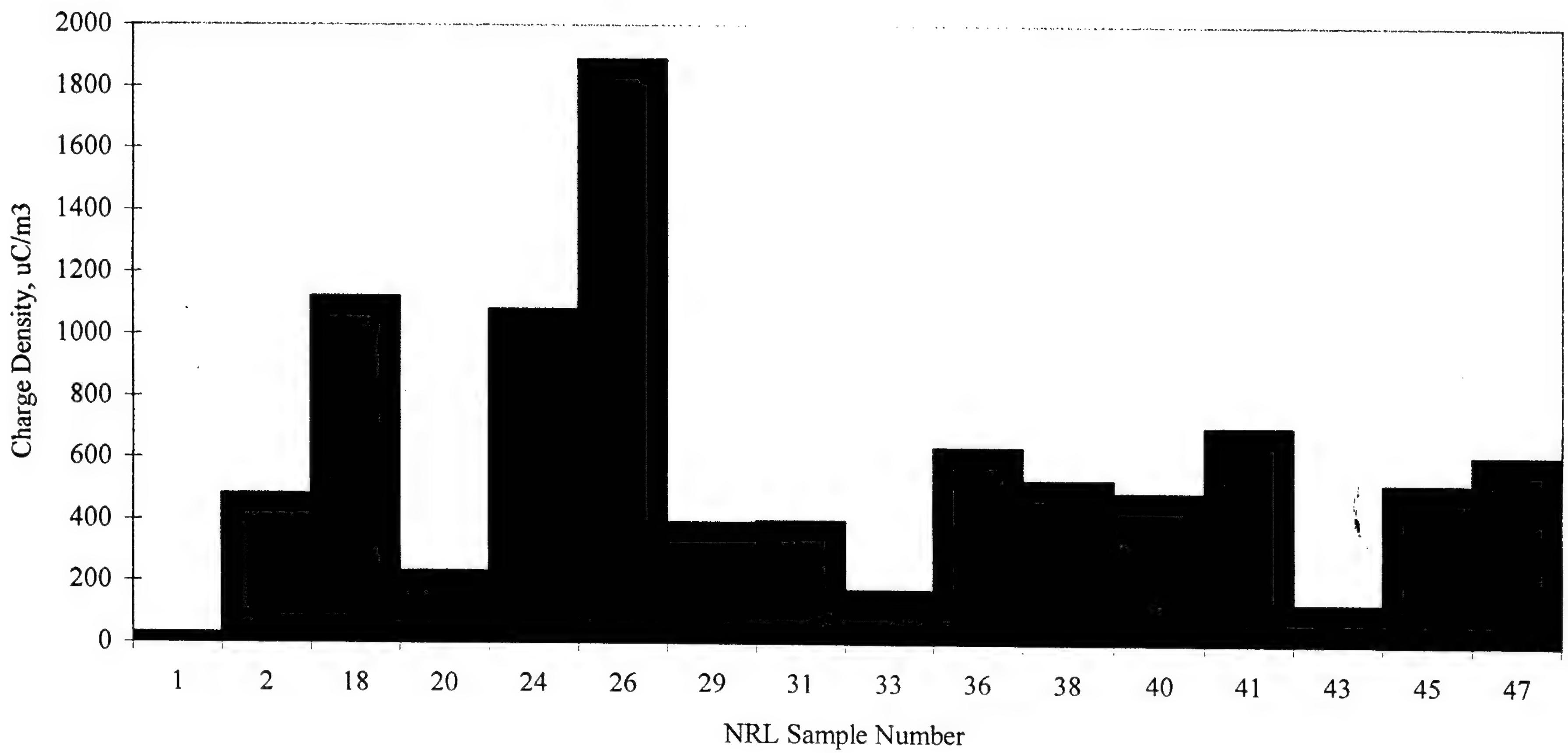


Fig. 7- Charging Tendency of Fuels Not Containing Betz Additive (Fuels in the Normal Jet A Conductivity Range Only) Filter: Type10 Paper



survey (3). In that survey, 99% of the Jet A samples had charging tendencies < 3000 μC/m$^3$ and the mean value was 680 μC/m$^3$. The exception in the present study was Sample 22, which also had a very high initial conductivity (322 pS/m) indicating that it probably contained a static dissipater additive.

For reference, a value of 4000 μC/m$^3$ has been selected as the threshold for high charging in the present study. This selection is based on the fact that only one sample out of a total of 338 Jet A samples in the 1975 CRC survey (3) had a charging tendency above 4000 μC/m$^3$.

Most of the samples containing the Betz additive had exceptionally high charging tendencies; most were over 10,000 μC/m$^3$ and up to a maximum of 26,100 μC/m$^3$ (Table 2 and Fig. 8). The highest values were obtained with the fuels having the highest conductivities, namely Samples 8, 10, 12, 13, 14, 15, and 17, which, as indicated above, probably contained Stadis 450 in addition to Betz. These values are in the range found for the most active fuel additive found in the previous study (4), namely Gulf 178, which was a corrosion inhibitor. This additive produced charge densities of 15,000 μC/m$^3$ at the 100 ppm level and 23,500 at the 1000 ppm level (Fig. 9).

The high charging indicated above for fuels containing the Betz additive is of little concern from the standpoint of an electrostatic hazard under <u>most</u> circumstances since the conductivities of the fuels are so high, i.e. above 90 pS/m. The high conductivity would permit most of the charge to dissipate in less than a second after it is generated. The possible exceptions where a hazard might occur despite the high conductivity are: during the filling of an empty filter vessel or when the fuel flows over a low conductivity reticulated foam.

The effect of the Betz additive on the charging tendencies of "normal" Jet A fuels using the Type 10 reference filter is seen more clearly in Table 3. The Betz additive increased the charging tendencies of eight of these samples above the 4000 μC/m$^3$ threshold, making them high charging samples. Curiously, one sample, Sample 26, had a decrease in charging tendency of 440 μC/m$^3$ after the addition of the Betz additive. For the remaining samples, the average increase in charging tendency was 5887 μC/m$^3$, a value somewhat skewed by two very high charging samples, i.e., Samples 40 and 46.

Although no overall correlation was found showing the effect of conductivity on charging tendency of fuels containing the Betz additive (Fig. 10), for a given fuel, the charging tendency was found to reach a maximum in the range of 150-250 pS/m (Fig. 11). This is in agreement with earlier work showing the effect of the static dissipater additive ASA-3 on the charging tendency of jet fuels (8) (Fig. 12).

Fig. 8- Charging Tendency of All Fuels Containing Betz Additive. Filter: Type 10Paper

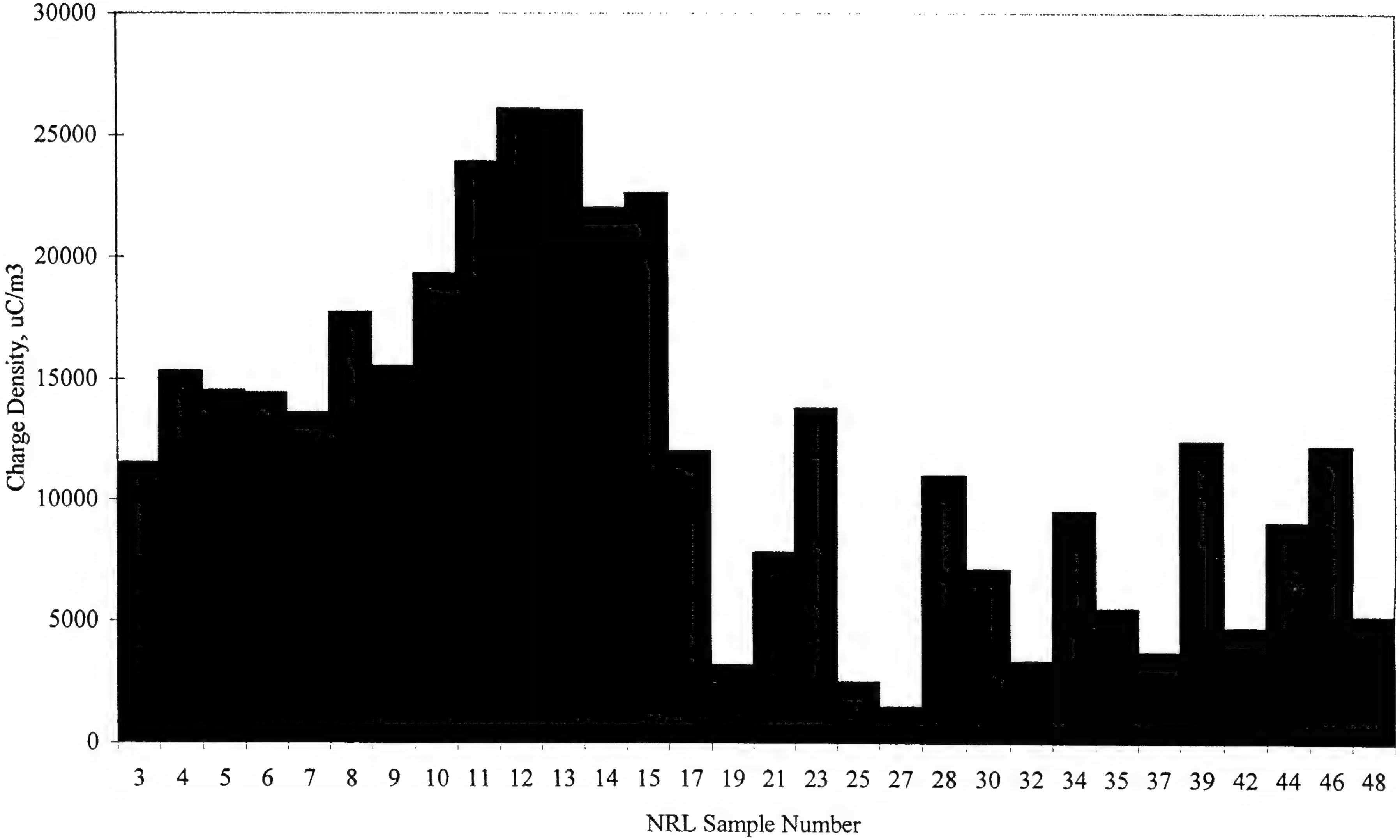


Fig. 9- Effect of Corrosion Inhibitors on Charging Tendency (Charge Density of Neat Fuel = 909 uC/m3). Filter: Type 10 Paper-Ref. 4

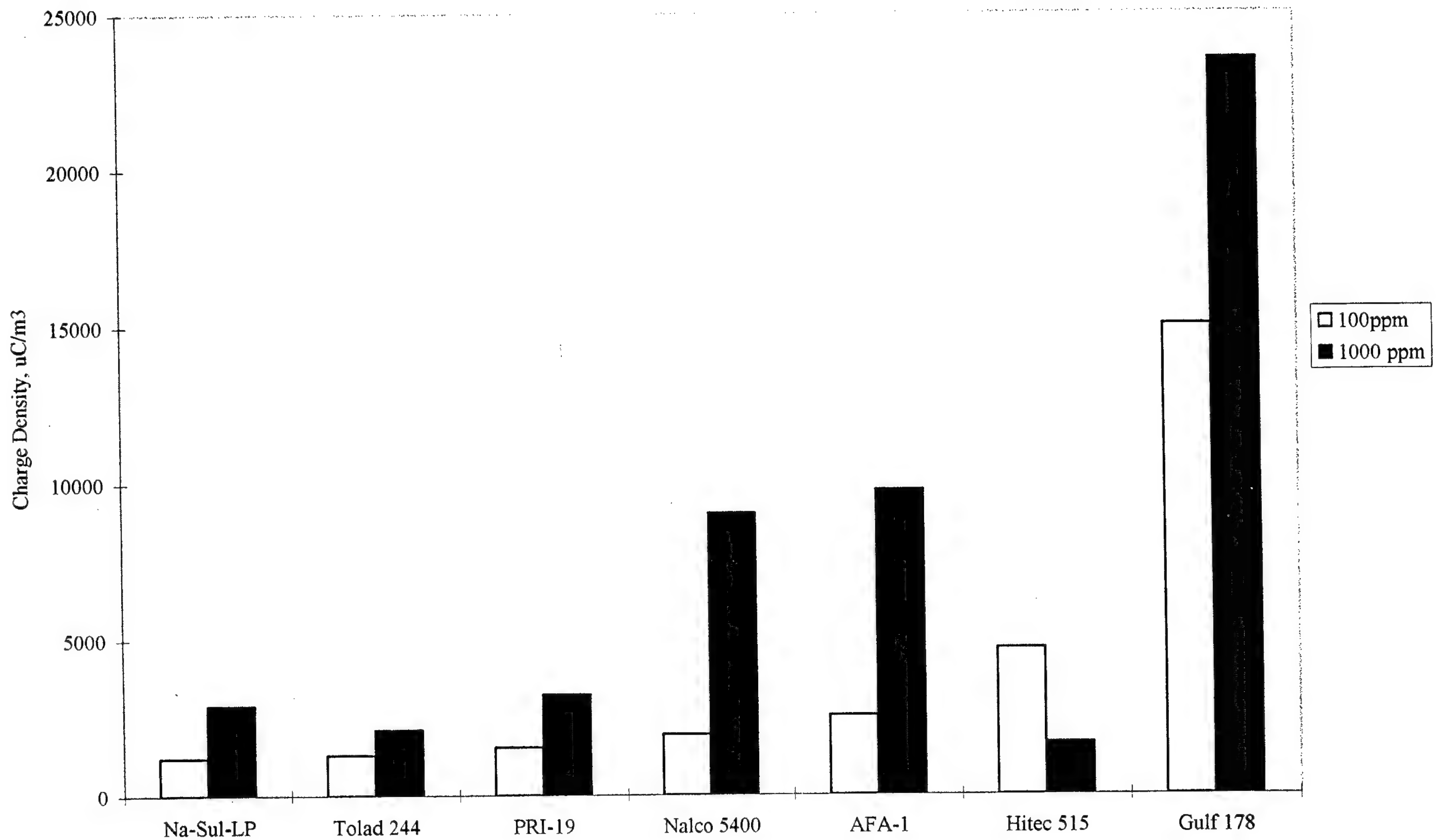


Fig. 10- Effect of Conductivity on Charging Tendency of Fuels Containing Betz Additive.  Filter: Type 10 Paper

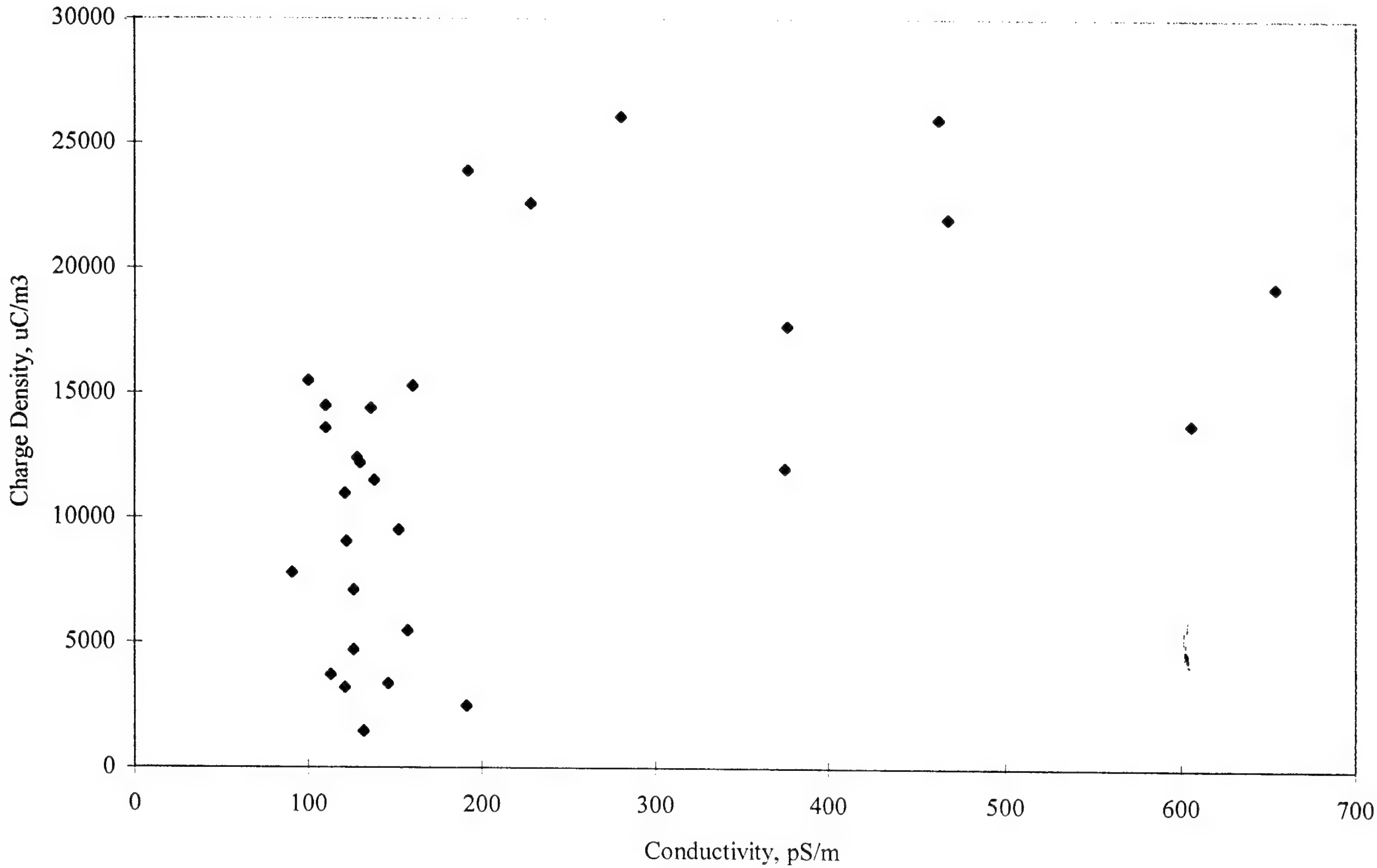
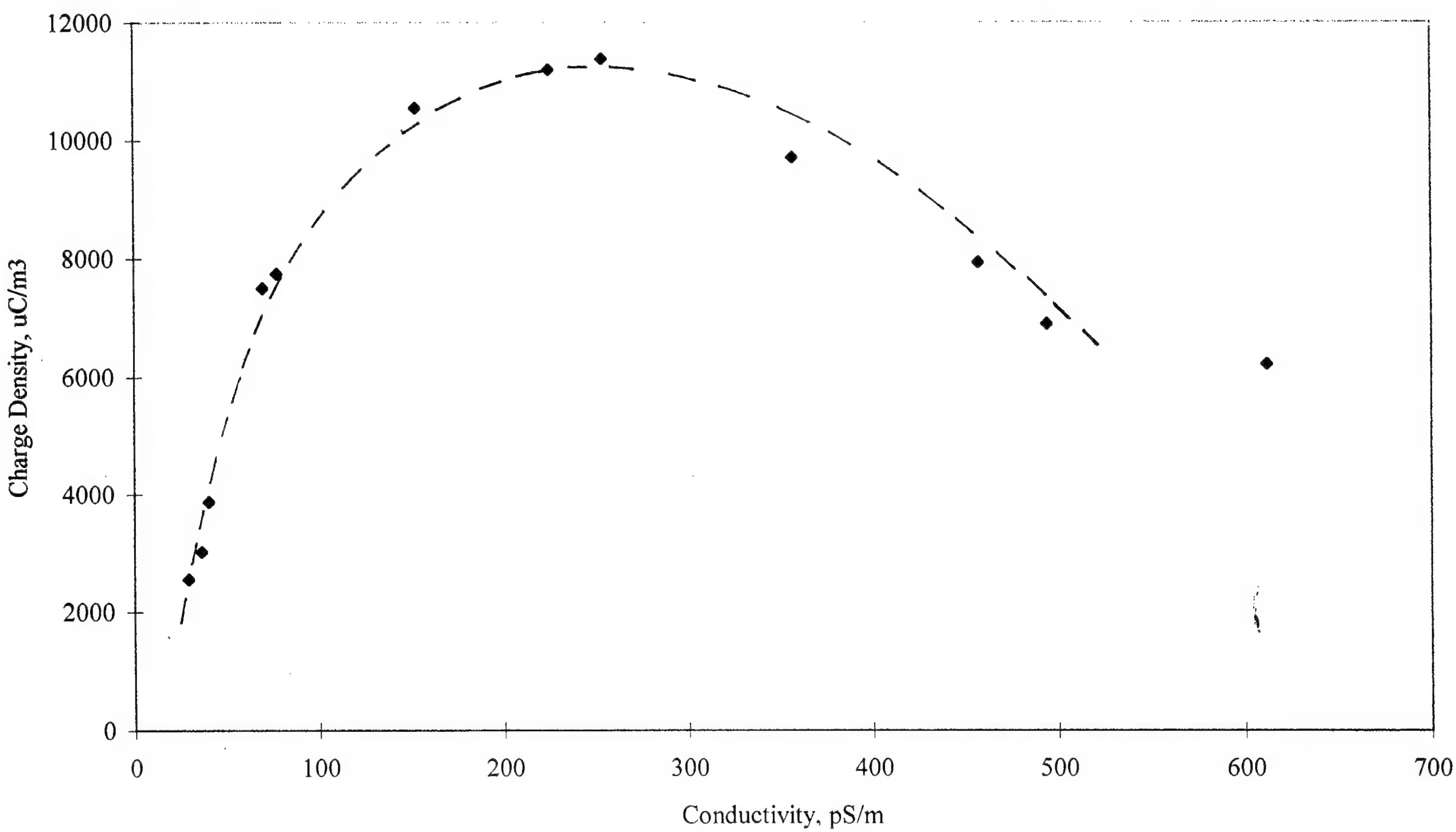


Fig. 11- Effect of Betz Additive on Charging Tendency of a Jet A Fuel (NRL Sample No. 34)



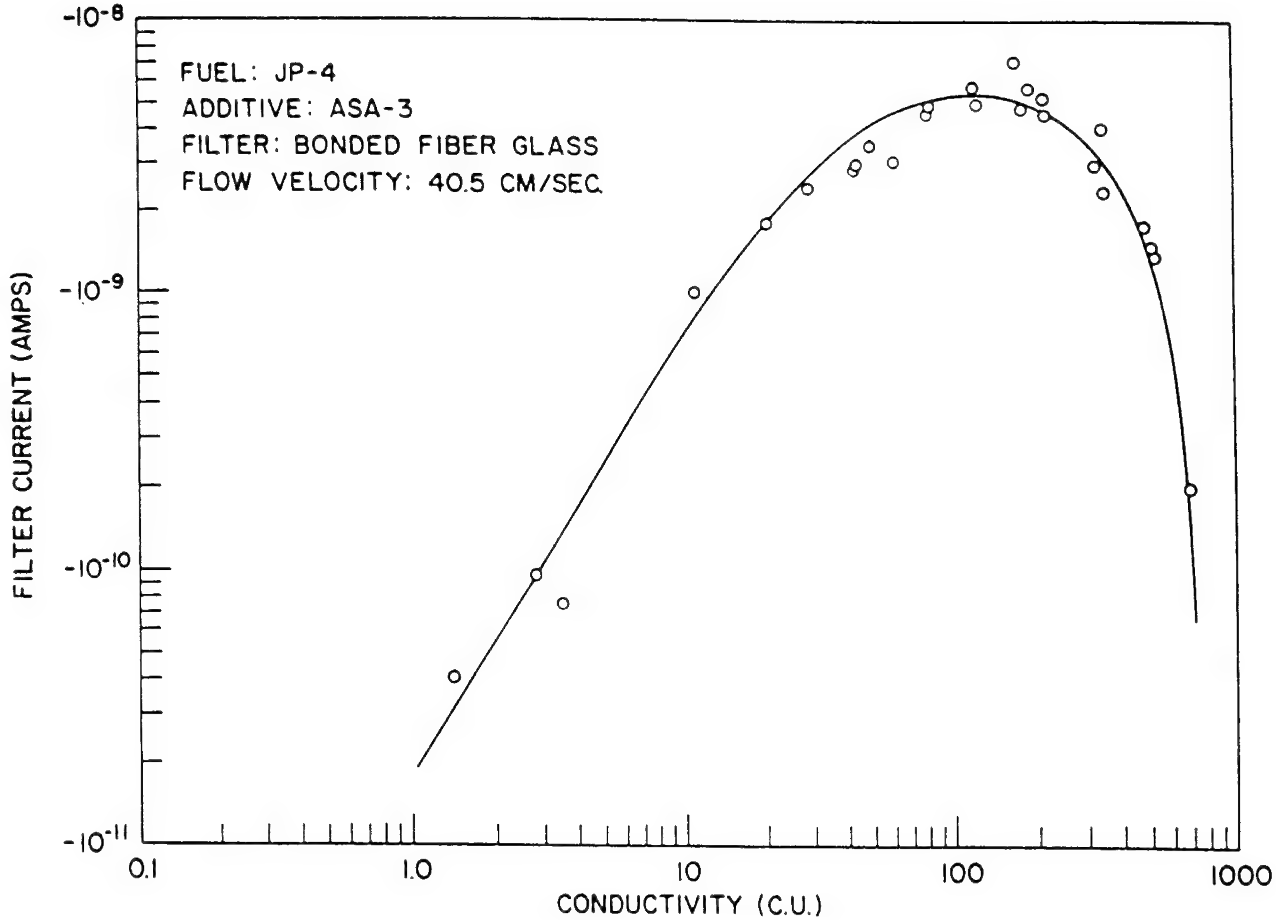



Fig.12 - Effect of conductivity of JP-4 fuel containing the static dissipator additive on filter current, gravity apparatus

## Effect of Stadis 450 on Conductivity and Charging Tendency

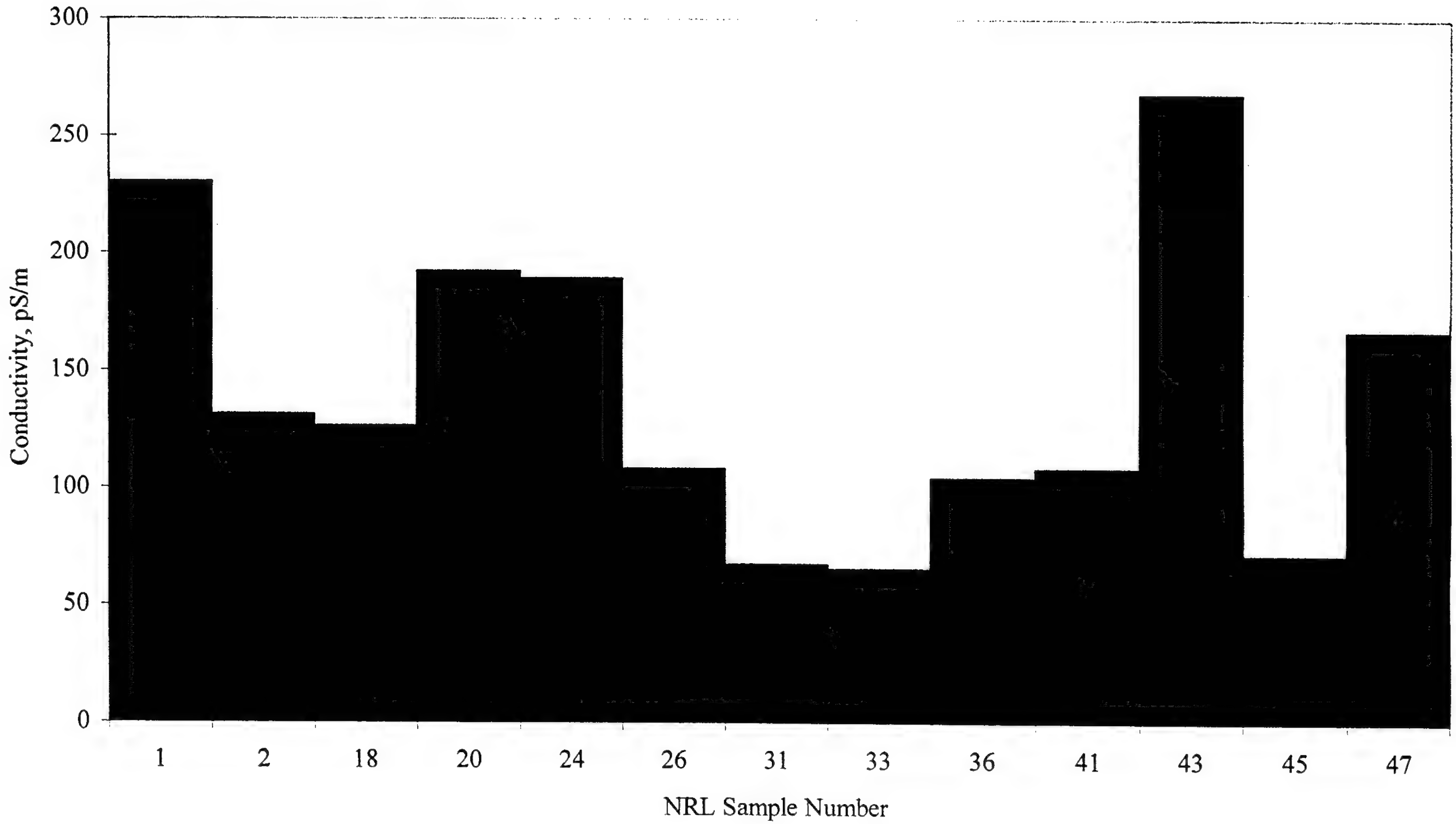
The addition of 1 ppm Stadis 450 increased the conductivities of most samples to above 100 pS/m (Table 4, Fig. 13.) However, fuels varied widely in their response to Stadis 450. Three samples, namely, Samples 31, 33, and 45, showed poor conductivity response to Stadis 450 and Samples 31 and 33 also showed correspondingly low charging tendencies. The average increase in conductivity for samples in the normal conductivity range (0.1 - 10 pS/m) was 138 pS/m after the addition of 1 ppm Stadis 450, and five samples were above 150 pS/m.

**Table 4 – Effect of 1 ppm Stadis 450 on Conductivity and Charging Tendency of Fuels Not Containing the Betz Additive (Filter: Type 10 Paper)**

| | | Conductivity, pS/m | | | Charge Density, μC/m³ | | |
|---|---|---|---|---|---|---|---|
| NRL* Sample No. | AF* POSF No. | Before Stadis | After Stadis | Δ k* | Before Stadis | After Stadis | Δ CD |
| **A. Samples in Normal Jet A Conductivity Range** | | | | | | | |
| 1 | 3498 Neat** | 0.15 | 230 | +230 | 38 | 3,350 | +3,312 |
| 2 | 3498 | 0.22 | 131 | +131 | 480 | 6,160 | +5,680 |
| 18 | 3551A | 2.86 | 126 | +123 | 1,120 | 1,700 | +580 |
| 20 | 3552A | 0.31 | 192 | +192 | 231 | 5,280 | +5,049 |
| 24 | 3554A | 9.44 | 189 | +180 | 1,080 | >519*** | +>561*** |
| 26 | 3555A | 3.43 | 108 | +105 | 1,890 | 6,100 | +4,210 |
| 31 | 3627B | 1.22 | 67.3 | +66 | 397 | 738 | +341 |
| 33 | 3633B | 1.84 | 65 | +63 | 171 | 720 | +549 |
| 36 | 3638B | 2.17 | 104 | +102 | 634 | 3,700 | +3,066 |
| 41 | 3593A | 3.76 | 108 | +104 | 702 | 2,500 | +1,798 |
| 43 | 3601A | 0.25 | 268 | +268 | 131 | >2,260 | +2,129 |
| 45 | 3602A | 0.43 | 70.6 | +70.3 | 519 | 2,680 | +2,161 |
| 47 | 3603A | 1.00 | 167 | +166 | 610 | 3,710 | +3,100 |
| **B. High Conductivity Samples** | | | | | | | |
| 16 | 3550A | 79**** | 255 | 176 | >180*** | 1,190 | +>1,010*** |
| 22 | 3553A | 322**** | 611 | 289 | 5,950 | 4,180 | -1770 |

* Average Δk for samples in normal Jet A conductivity range: 138 pS/m
** This sample did not contain FSII or CI
*** Unable to achieve equilibrium with this sample
**** High initial conductivity suggests that this sample already contained Stadis 450

Fig. 13- Conductivity of Fuels Containing Stadis 450, But Not Betz Additive



The charging tendencies of fuels not containing the Betz additive increased over a wide range (519 - 6160 $\mu C/m^3$ (Table 4 and Fig. 14)) upon the addition of 1 ppm Stadis 450. Three of the samples, namely, Samples 2, 20 and 26, were above 4000 $\mu C/m^3$ , and hence would be considered high charging. However, as with the Betz additive, the high charging would not be indicative of an electrostatic hazard under <u>most</u> circumstances as long as the conductivity of the fuel were sufficiently high.

For samples containing the Betz additive, the average increase in conductivity was 252 pS/m after the addition of 1 ppm Stadis 450 (Table 5 and Fig. 15). This is considerably more

**Table 5 – Effect of 1 ppm Stadis 450 on Conductivity and Charging Tendency of Fuels Containing the Betz Additive (Filter: Type 10 Paper)**

| | | Conductivity, pS/m | | | Charge Density, $\mu C/m^3$ | | |
|---|---|---|---|---|---|---|---|
| NRL* Sample No. | AF* POSF No. | Before Stadis | After Stadis | Δ k* | Before Stadis | After Stadis | Δ CD |
| **A. Samples in the Normal Conductivity Range for Betz Additive** | | | | | | | |
| 3 | 2827 | 138 | 339 | +201 | 11,500 | 20,500 | +9,000 |
| 4 | 2926 | 160 | 382 | +222 | 15,300 | 19,800 | +4,500 |
| 5 | 3055 | 110 | 339 | +229 | 14,500 | 19,200 | +4,700 |
| 6 | 3119 | 136 | 380 | +244 | 14,400 | 17,500 | +3,100 |
| 7 | 3166 | 110 | 343 | +233 | 13,600 | 16,300 | +2,700 |
| 9 | 3084 | 100 | 352 | +252 | 15,000 | 19,300 | +4,300 |
| 11 | 3476 | 192 | 536 | +344 | 23,900 | 23,000 | -900 |
| 19 | 3551B | 121 | 325 | +204 | 3,210 | 13,200 | +9,990 |
| 21 | 3552B | 90.5 | 389 | +298 | 7,810 | 16,600 | +8,790 |
| 25 | 3554B | 191 | 451 | +260 | 2,490 | 9,210 | +6,720 |
| 27 | 3555B | 132 | 355 | +223 | 1,452 | 6,770 | +5,318 |
| **B. High Conductivity Samples** | | | | | | | |
| 8 | 3219 | 376** | 565 | +189 | 17,700 | 16,100 | -1,600 |
| 10 | 3475 | 654** | 906 | +252 | 19,300 | 12,200 | -7,100 |
| 12 | 3477 | 280** | 562 | +282 | 26,100 | 20,000 | -6,100 |
| 13 | 3478 | 463** | 739 | +276 | 26,000 | 20,600 | +600 |
| 14 | 3479 | 468** | 778 | +310 | 22,000 | 12,700 | -9,300 |
| 15 | 3480 | 228** | 504 | +276 | 22,600 | 24,300 | +1,700 |
| 17 | 3550B | 375** | 550 | +175 | 12,000 | 9,760 | -2,240 |
| 23 | 3553B | 606** | 921 | +315 | 13,800 | 10,200 | -3,600 |

* For samples containing the Betz additive: Range, 175-344 pS/m; Average, 252 pS/m

** High initial conductivity indicates that this sample may have been previously treated with Stadis 450

Fig. 14- Charging Tendency of Fuels Containing Stadis 450, But Not Betz Additive. Filter: Type 10 Paper

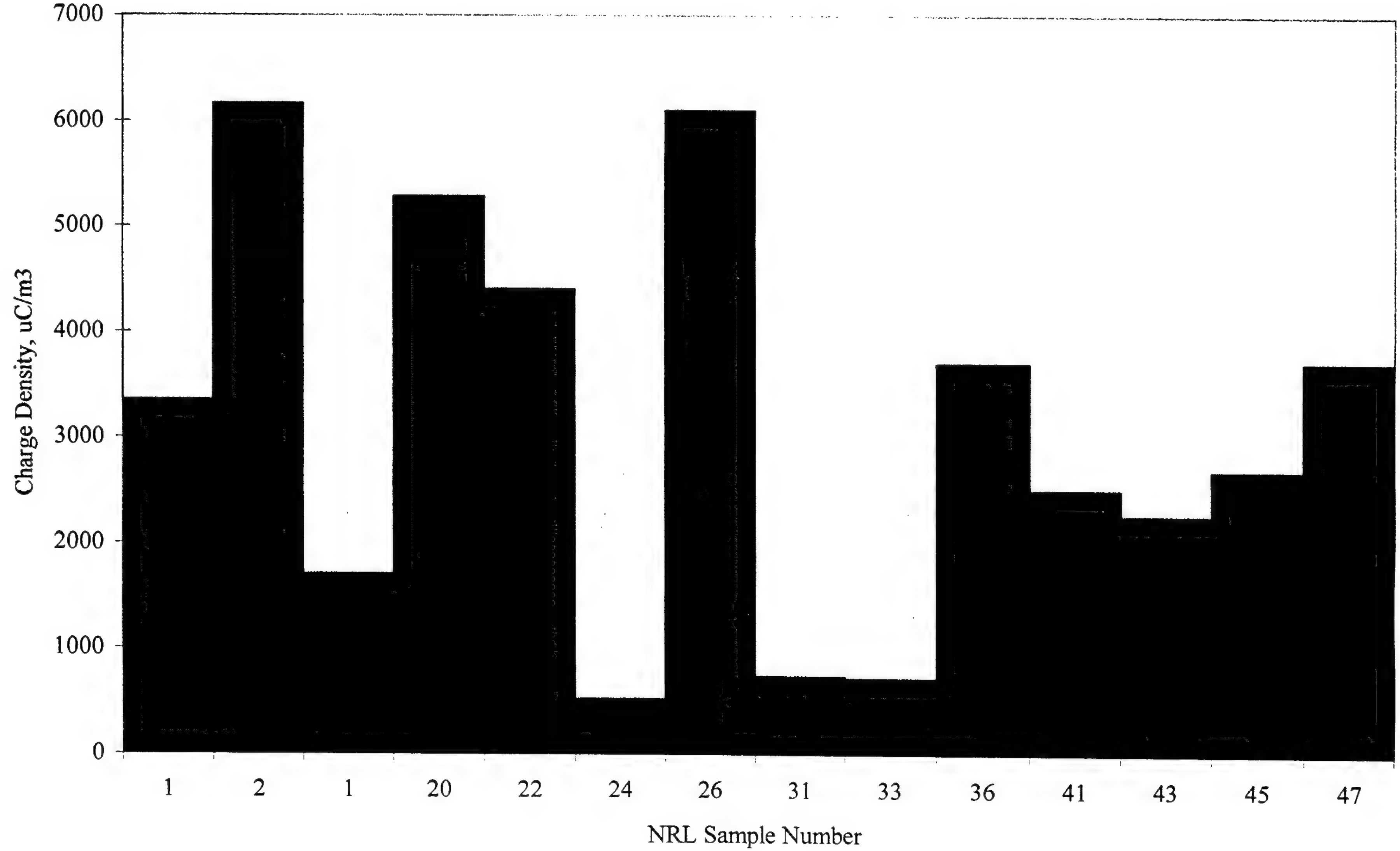
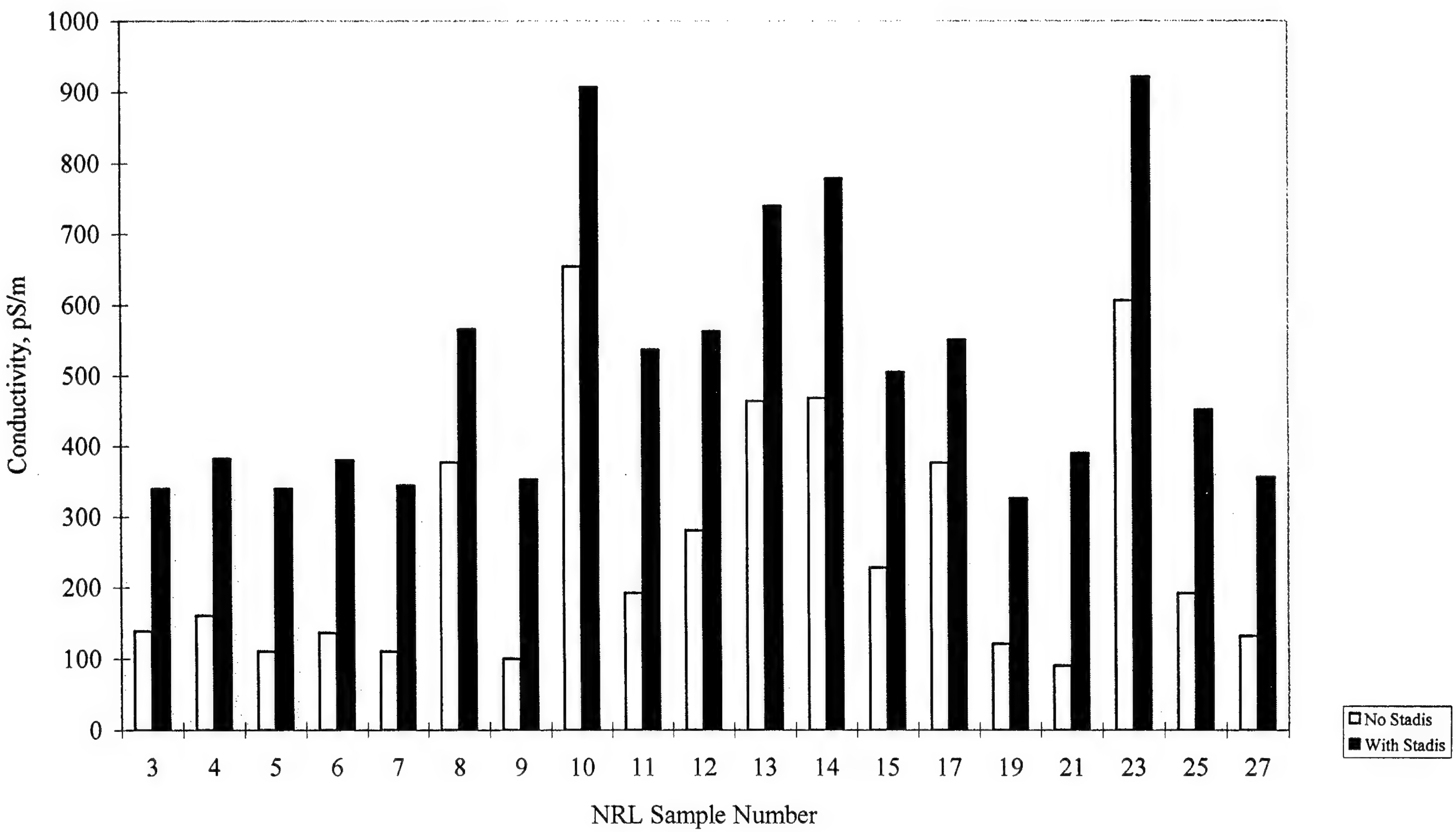


Fig. 15- Effect of 1 PPM Stadis 450 on Conductivty of Fuels Containing Betz Additive



than the increase of 138 pS/m obtained when Stadis was added to fuels not containing the Betz additive, indicating that Stadis is more active in fuels containing the Betz additive. Some of the samples, e.g. Samples 8, 10, 12, 13 14, 15, 17 and 23, had unusually high conductivities before the addition of Stadis 450, indicating that they may have been previously treated with Stadis 450.

The addition of 1 ppm of Stadis 450 increased the charging tendencies of most of the samples containing the Betz additive except for the high conductivity samples, i.e., above 280 pS/m (Table 5, Fig. 16). As shown earlier (Figs. 11 and 12), the charging tendency of a fuel containing a particular additive increases with conductivity up to a certain conductivity level, depending on the flow velocity, and then begins to fall off at higher conductivities. For the flow velocity used in this study, the charging tendency begins to fall off above 250 pS/m for fuels containing the Betz additive (Fig. 11).

The charging tendencies for fuels containing both Betz and Stadis were all quite high, in the range of 6770 – 24,300 $\mu C/m^3$ (Table 5). However, such high charging is of little concern from the standpoint of an electrostatic hazard under <u>most</u> circumstances, as explained above, since the conductivities of the fuels are all so high (above 325 pS/m).

**Charging Tendency Measurements on Various Filter Media**

Charging tendency measurements were made on coalescer, separator and monitor cartridge media supplied by three manufacturers. In addition, an experimental coalescer material, designated "Type 1," was also tested. Although the media were intended for use on JP-8 + 100 fuels, three different types of fuels were tested:

1) Fuels not containing Betz or Stadis 450

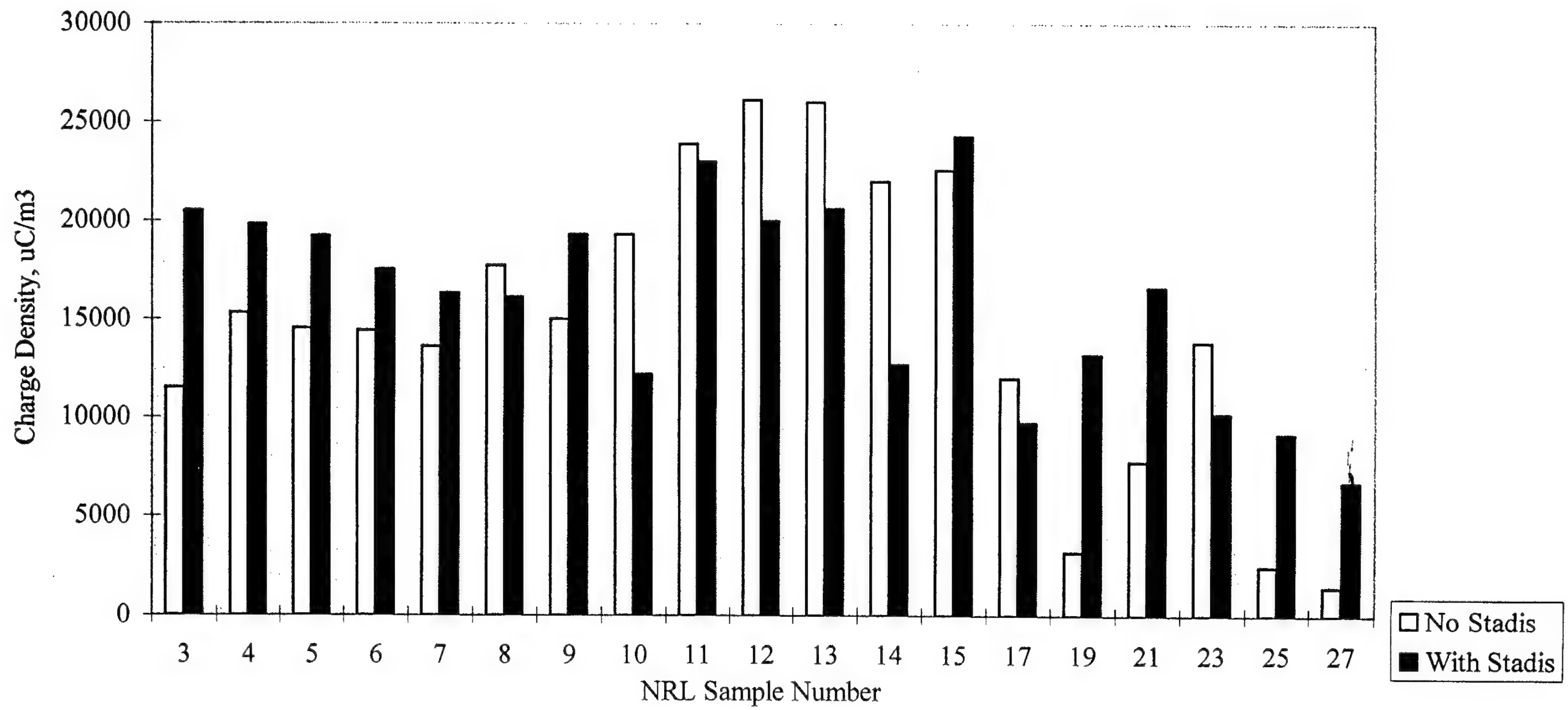
2) Fuels containing Betz but no Stadis

3) Fuels containing Stadis but no Betz.

All samples contained FSII and CI unless indicated otherwise.

The results of the charging tendency measurements for fuels on the various filter media are given in Table 6. The symbols (< and >) preceding the charge density values for certain samples indicate that equilibrium was not achieved for these samples after three passes of fuel through the filter: the > symbol indicates that the filter current was still increasing after three passes of the fuel, and the < symbol means that the current was still decreasing after three passes. The current reading at the end of the third pass was used to calculate the charge density value shown in the table.

Fig. 16- Effect of 1 PPM Stadis 450 on Charging Tendency of Fuels Containing Betz Additive. Filter: Type 10 Paper



## Table 6 – Charging Tendency of Fuels on Coalescer Media

| NRL Sample No. | 2D | 29 | 28 | 30 | 34 | 31* | 33* | 38* | 40** | 97-55**+ | 47* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AF POSF No. | 3428D | --- | 3166 | 3627A | 3638 | 3627B* | 3633B* | 3639B* | 3640B** | | 3603* |
| | Samples with no Betz or Stadis | | Samples with Betz, no Stadis | | | Samples with Stadis, no Betz | | | | | |
| Conductivity, pS/m | 0.22 | 4.25 | 121 | 126 | 152 | 65 | 65 | 86 | 99 | 101 | 167 |
| Description of Medium | Charge Density, µC/m$^3$ | | | | | | | | | | |
| 5 oz. Felt | -2 | | <55 | 451 | <27 | -2,170 | -1,270 | -3,800 | -1,680 | -3,360 | |
| 8 oz. Felt | -4 | -46 | 324 | 145 | >-366 | -3,770 | -3,230 | -4,030 | -3,040 | -2,140 | |
| 10 oz. Felt | -4 | -18 | >-305 | >445 | >-598 | -7,080 | -5,120 | -9,940 | -7,320 | -7,750 | |
| Fiberglass, Coarse | -4 | -67 | >-268 | >244 | <48 | | -683 | | | -2,010 | |
| Fiberglass, Fine | -3 | | >515 | 101 | -6 | | -1,400 | | | -9,760 | |
| Fiberglass, Fine | >2 | >1,100 | >-1,450 | 238 | 92 | | -1,510 | | | -15,600 | |
| Fiberglass Screen | | | 9 | | | | | | | | |
| Fiberglass Paper, Top | -16 | -472 | -720 | N/A | -671 | -2,560 | | -4,100 | | | -4,700 |
| Fiberglass Paper, Mesh | -18 | -381 | -860 | N/A | 418 | >-3,840 | | -6,100 | | | -5,550 |
| Fibrous Material | -4 | -329 | -586 | N/A | >-37 | -3,380 | | -6,700 | | | -9,330 |
| Glass Substrate | -24 | | -720 | -195 | -347 | | -2,200 | | -3,430 | -3,569 | |
| Glass Substrate | -18 | | -641 | >-50 | >-223 | | -1,710 | | | >-4,390 | |
| Glass Sheet | -32 | | 1,040 | -305 | >-407 | -4,390 | -2,540 | | 4,070 | -3,750 | |
| Knit (Cotton), Off-White | 0 | -12 | -30 | N/A | -9 | -1,020 | -1,120 | -1,040 | | | -189 |
| Knit (Synthetic), White | 3 | -52 | >-488 | N/A | 100 | >-3,870 | -4,850 | -4,320 | | | -287 |
| Polyester | 0 | 5 | <33 | 171 | <26 | | -622 | | | -799 | |
| Polyester | -4 | | -302 | -87 | -317 | | -1,550 | | | -1,070 | |
| Polyester Non-Woven Sleeve A | -18 | -132 | -404 | -154 | -262 | -5,110 | | -7,750 | | | |
| Polyester Non-Woven Sleeve B | -5 | -14 | -132 | -130 | -43 | -732 | | -1,100 | | | |
| Polyester Spun Bound | 2 | | 118 | | | | | | | 409 | |
| Prefilter Extruded Net | -0.6 | 0 | 10 | <10 | 16 | -85 | | -96 | | | |
| Prefilter Glass Fiber Material | 1.5 | 4 | <21 | <111 | 75 | -142 | | >-458 | | | |
| Prefilter Non-Woven Material | -30 | -350 | -1,460 | -1,710 | -1,190 | >-3,540 | | >-4,510 | | | |
| Screen, Aluminum | | | 8 | | | | | | | | |
| Sock, Cotton | -2 | | 13 | | | | | | | 1,530 | |
| Type 1 Coalescer Medium | 155 | 1220 | >19,800 | >22,500 | >21,700 | >1,190 | | >4,390 | | | |

+ NRL 97-55 is a Jet A with no additives
* Plus 1 ppm Stadis 450
** Plus 2 ppm Stadis 450

An example of a rising filter current is shown in Fig. 17 which is the curve obtained for Sample 28 on Type 1 experimental coalescer material. In this case, the charging tendency reported in Table 6 for Sample 28 (> 19,800 $\mu C/m^3$) is the value calculated from the final filter current (-3.45 x $10^{-8}$) on Fig. 17, which, as shown in the figure, appears to be reaching equilibrium at the end of the run. This sample produced a flat, equilibrium filter current on the Type 10 reference paper as shown in Fig. 18. In this case, the charge density is calculated from the current reading midway through the test as required in the test procedure (2). The reason why the fuel does not come to equilibrium on the Type 1 filter appears to be related to the fact that this filter is denser than the Type 10 medium, and hence has more surface area available for the charge separation process to occur on. Hence, more time is required for equilibrium to take place with this type of filter than is currently available using the EXXON Mini-Static Test procedure.

It should be noted that the EXXON Mini-Static Tester was designed to measure the charging tendency of a fuel on a single layer of filter medium, such as the Type 10 reference filter. In practice, most filters consist of several layers of different media. The subsequent layers can either augment the charging of the fuel if they produce the same sign of charge as the initial filter medium, or decrease the overall charge if they happen to produce charge of the opposite sign to the initial filter. The EXXON Mini-Static Tester would show the net effect of the charging by the different layers, assuming of course, that equilibrium was reached during the relatively short flow time of 30 seconds used by the Mini-Static Tester.

**Charging on Fuels Containing Neither Betz nor Stadis**

As shown in Table 6, fuels containing neither Betz nor Stadis produced low levels of charge on all coalescer media, including Type 1 coalescer medium. These same fuels (Samples 2D and 29) produced low levels of charge on Type 10 paper - see Table 1. Previous studies have shown that fuels that charge poorly on Type 10 paper, also charge poorly on other coalescer media (4).

**Charging of Fuels Containing the Betz Additive**

Fuels containing the Betz Additive, but no Stadis, produced low levels of charge on all coalescer media except the experimental Type 1 medium. The levels of charge obtained on this material (>19,000 $\mu C/m^3$) were higher than the values obtained with most fuels on the Type 10 paper - see Table 2. Hence, a more detailed study of charging on the Type 1 coalescer medium was carried out and is discussed later in this report.

**Charging of Fuels Containing Stadis 450**

The charge levels obtained for fuels containing Stadis 450 were generally higher than the values obtained with the Betz additive on all coalescer media except the experimental Type 1 medium. Of particular interest is the high charging obtained with the Stadis additive on the white knit synthetic material. Normally, knit materials are fairly low charging. Also, high charging was obtained for samples containing Stadis 450 on fiberglass and felt. In fact, charging

Fig. 17-Rising Filter Current for Fuel Sample 28 Using Type 1 Filter

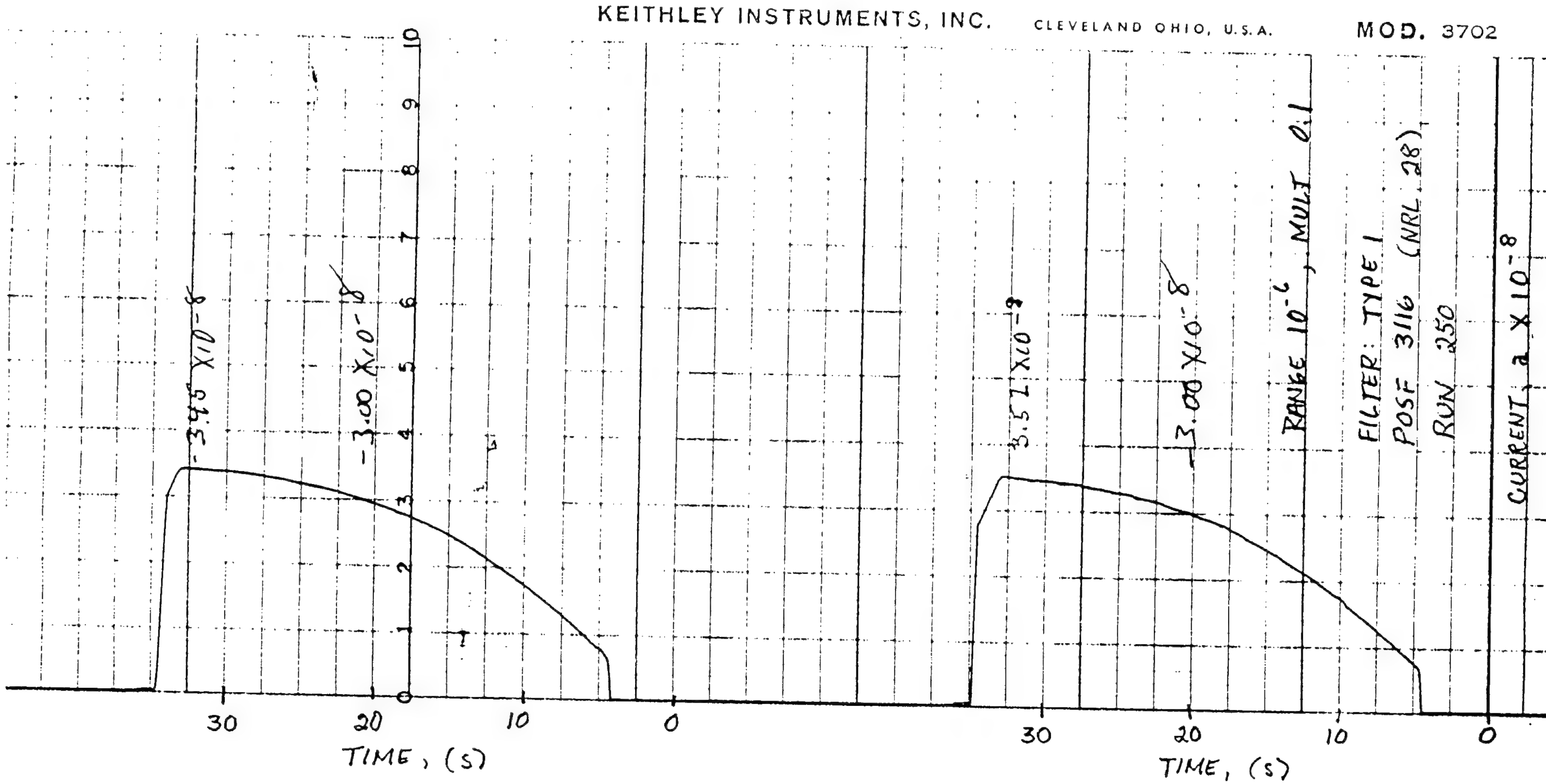
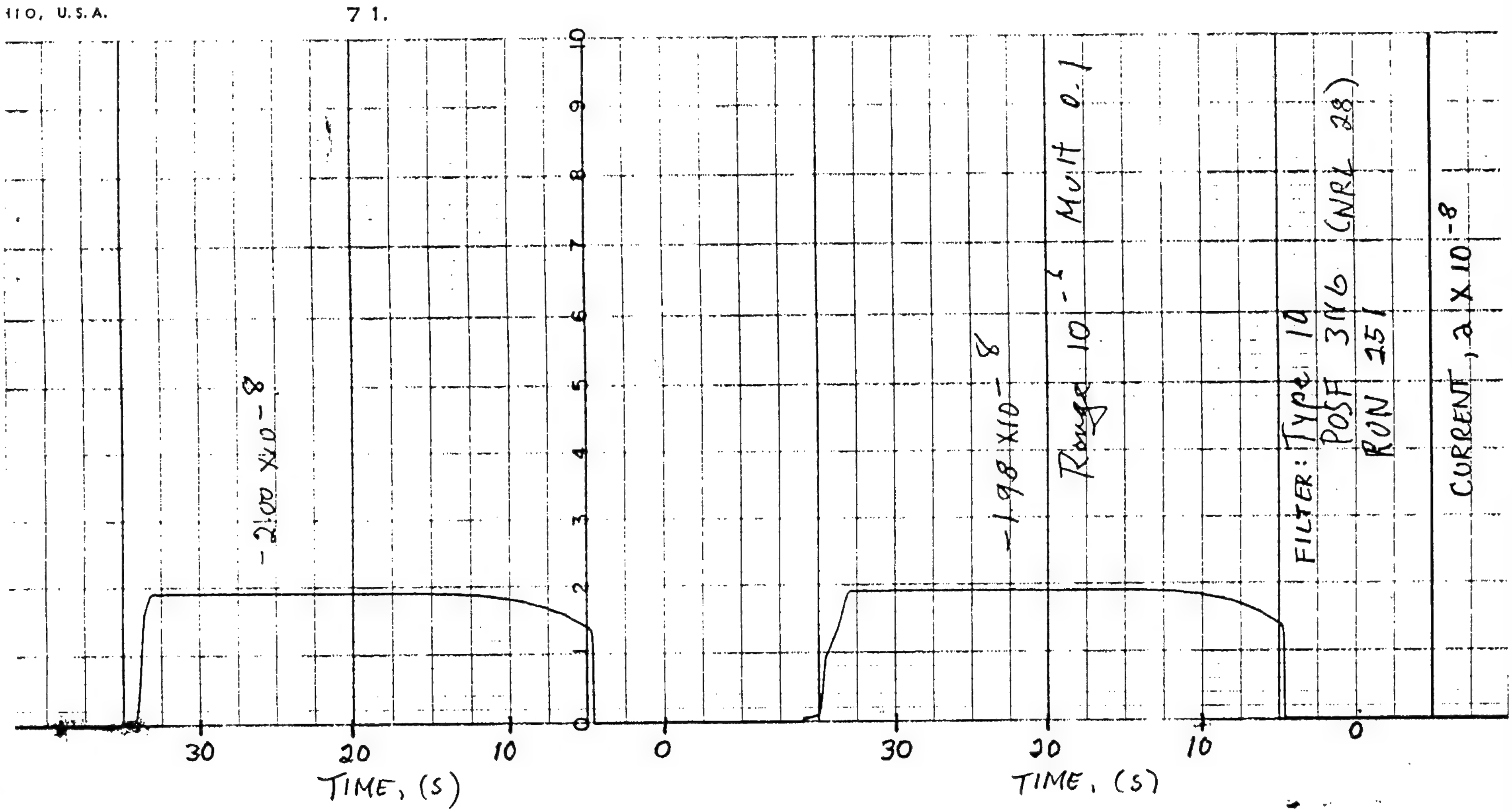


Fig. 18-Normal (Flat) Filter Current Curve for Fuel Sample 28 Using Type 10 Filter



of fuels containing Stadis 450 on felt appears to be related to the density of the felt (Fig. 19): the heavier the felt, the higher the charging.

### Charging on Separator Media

As expected, no significant charging was found for any of the fuels on any of the separator media except Type 10 (Table 7). This is because all of the separator media, except Type 10 paper, have a fairly open structure with relatively low surface area on which charge separation can take place. The high charging on the Type 10 paper was the reason this paper was selected as a reference filter for testing the charging tendency of fuels.

### Charging on Monitor Cartridge Media

Charging of the fuels with no additives and with fuels containing the Betz additive was low on all of the monitor cartridge media (Table 8). However, high charging was found for certain fuels containing Stadis 450 on the media paper (Layer 4) and on the superabsorbent and absorbent media (Layers 5 and 6) using Sample 36. A second series of tests using the same base fuel and 2 ppm Stadis 450 didn't show much increase in charging on Layer 4, but did show a decrease in charging on Layers 5 and 6. The decrease is due to the high conductivity of the fuel (373 pS/m). As explained earlier, the charging tendency begins to fall off as the conductivity goes above 250 pS/m (Fig. 11).

### Comparison of Charging on Type 10 and Type 1 Filter Media

Since high charging was observed during the preliminary testing with the Type 1 experimental coalescer medium, a series of tests were conducted to compare the charging tendency of fuels on this medium with charging on the standard Type 10 filter. Several different fuels were used, namely:

1) Fuels containing neither Betz nor Stadis

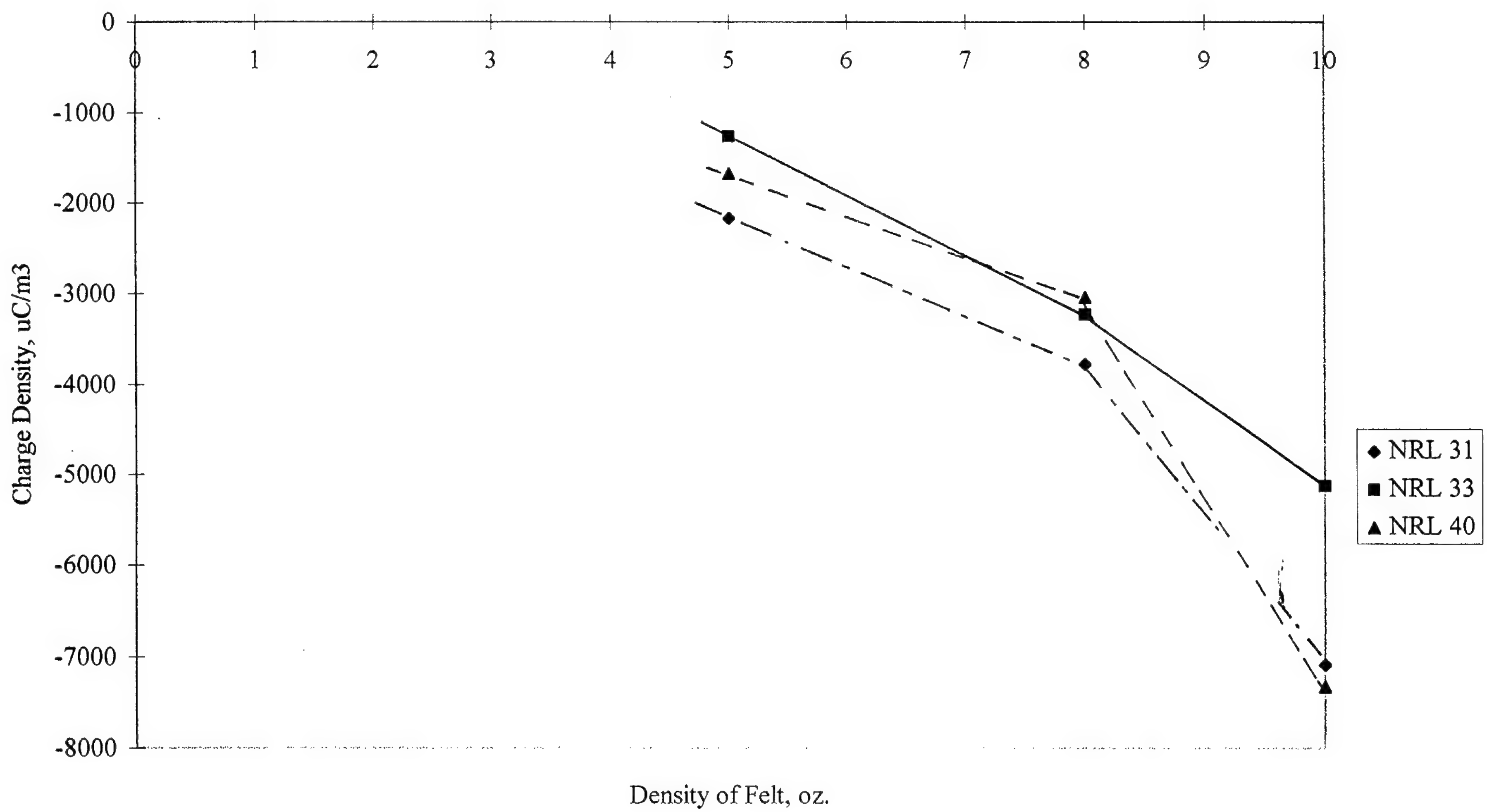
2) Fuel containing Betz, but not Stadis

3) Fuel containing Stadis, but not Betz

4) Fuels containing both Betz and Stadis

The results of these tests are given in Tables 9-12.

Fig. 19- Charging of Fuels Containing 1 PPM Stadis 450 on Felt Coalescer Medium



## Table 7 – Charging Tendency of Fuels on Separator Media

| **NRL Sample No.** | **2D** | **31** | **40** | **28** | **34** | **38** | **47** | **28 + 1 ppm Stadis** | **10/11 + 1 ppm Stadis** |
|---|---|---|---|---|---|---|---|---|---|
| **AF POSF No.** | **3428D** | **3627B** | **3640B** | **3166** | **3638A** | **3639B** | **3603A** | **3166 + Stadis** | **3475/3476 + 1 ppm Stadis** |
| | **Samples with no Betz or Stadis** | | | **Samples with Betz, no Stadis** | | **Samples with Stadis, no Betz** | | **Sample with Betz and Stadis** | |
| **Conductivity, pS/m** | 0.22 | 1.22 | 6.10 | 121 | 152 | 86 | 167 | 342 | 452 |
| **Separator Medium** | Charge Density, $\mu C/m^3$ | | | | | | | | |
| Teflon-Coated Screen | 0 | 3 | -3 | 6 | 15 | -73 | -32 | 17 | 11 |
| Nylon-Treated PVO Screen | 2 | 4 | -2 | 442 | 125 | -201 | 93 | 1,100 | 34 |
| Type 10 Reference Paper | 348 | 397 | 488 | 10,980 | 10,700 | 454 | 3,710 | 17,980 | 22,700 |

**Table 8 – Charging of JP8 Fuels on Monitor Cartridge Media**

| NRL Sample No. | | 2D | 2B | 33 | 40 | 39 | 28 | 32 | 34 | 2B* | 1*,** | 36* | 36*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AF POSF No. | | 3428D | 3428B | 3633B | 3640B | 3640A | 3166 | 3633A | 3638 | 3428B | 3428* | 3638B* | 3638B + 2 ppm Stadis |
| | | Samples with no Betz or Stadis | | | | Samples with Betz, no Stadis | | | | Samples with Stadis, no Betz | | | |
| Conductivity, pS/m | | 0.22 | 0.81 | 1.84 | 6.10 | 128 | 131 | 146 | 152 | 55.4 | 176 | 104 | 373 |
| Cartridge | | | | | | | | | | | | | |
| Layer | Description | Charge Density, $\mu C/m^3$ | | | | | | | | | | | |
| 1 | 25 Micron Paper | -27 | -75 | -70 | -95 | >3,660 | -381 | -272 | >-134 | -793 | -695 | -2,300 | >-35 |
| 2 | Absorbent Media | -4 | -9 | -16 | -80 | 0 | -67 | -33 | -17 | -580 | -311 | -1,230 | -134 |
| 3 | Media Paper | -3 | 6 | -9 | -21 | >233 | 246 | -6 | 0 | -204 | -73 | >10 | >29 |
| 4 | Media Paper | -2 | 34 | >-37 | -80 | >1,650 | >-439 | 216 | 66 | -500 | -256 | >11,700 | >12,200 |
| 5 | Media Superabsorbent (Polyolefin) | -22 | -75 | -171 | -280 | -123 | -125 | -280 | -176 | -2,740 | -1,930 | -4,010 | -952 |
| 6 | Media Absorbent | -12 | -11 | -108 | -300 | -66 | -186 | -134 | -127 | -2,260 | -2,110 | -4,260 | -534 |
| 7 | Media Spun bound Polyester | -1 | -6 | -15 | -27 | 605 | >-165 | 0 | 13 | -280 | -211 | -50 | -73 |

* Plus 1 ppm Stadis 450
** Sample 1 contained no FSII or CI
*** Plus 2 ppm Stadis 450

**Table 9 – Charging Tendency of Fuels Not Containing Betz or Stadis 450 on Type 10 and Type 1 Filter Media**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Filter Medium | |
|---|---|---|---|---|
| | | | Type 10 | Type 1 |
| | | | Charge Density, $\mu C/m^3$ | |
| 18 | 3551A | 8.73 | 866 | >1,830 |
| 20 | 3552A | 0.14 | 290 | 101 |
| 24 | 3554A | 7.35 | 793 | 1,090 |
| 26 | 3555A | 2.33 | 1,530 | >2,440 |
| 2D | 3428B | 0.81 | 573 | 436 |
| 2D | 3428D | 0.22 | 348 | 155 |
| 97-55 | | 0.63 | 677 | 1,070 |
| 29 | | 4.25 | 392 | >1,220 |
| 31 | 3627B | 1.22 | 397 | >445 |
| 33 | 3633B | 1.84 | 171 | 205 |
| 36 | 3638B | 2.17 | 634 | >281 |
| 38 | 3639B | 2.30 | 528 | >2,074 |
| 40 | 3640B | 6.10 | 488 | >427 |

**Table 10– Charging Tendency of Fuels Containing Betz, but not Stadis 450, on Type 10 and Type 1 Filter Media**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Filter Medium | |
|---|---|---|---|---|
| | | | Type 10 | Type 1 |
| | | | Charge Density, $\mu C/m^3$ | |
| 17 | 3550B | 380 | 13,400 | >25,000 |
| 19 | 3551B | 121 | 5,190 | 10,100 |
| 21 | 3552B | 96 | 8,780 | >20,100 |
| 23 | 3553B | 634 | 13,400 | >23,500 |
| 25 | 3554B | 196 | 5,000 | >7,690 |
| 27 | 3555B | 139 | 2,260 | >22,100 |
| 4 | 2926 | 168 | 14,600 | >19,500 |
| 5 | 3055 | 120 | 12,900 | >23,200 |
| 6 | 3119 | 148 | 12,000 | >22,000 |
| 7 | 3166 | 116 | 12,200 | >23,800 |
| 8 | 3219 | 426 | 16,200 | >22,000 |
| 9 | 3084 | 104 | 12,400 | >21,700 |
| 10/11 | 3475/3476 | 447 | 20,000 | >15,600 |
| 12 | 3477 | 188 | 24,700 | >17,100 |
| 13 | 3478 | 385 | 24,700 | >18,900 |
| 14 | 3479 | 283 | 22,600 | >17,100 |
| 15 | 3480 | 238 | 23,900 | >14,640 |
| 30 | 3627A | 126 | 7,110 | >22,600 |
| 32 | 3633A | 146 | 3,355 | >17,385 |
| 35 | 3638A | 157 | 5,490 | >17,700 |
| 37 | 3639A | 113 | 3,730 | >20,700 |
| 39 | 3640A | 128 | 12,400 | >17,100 |

**Table 11– Charging Tendency of Fuels Containing Stadis 450, but no Betz, on Type 10 and Type 1 Filter Media**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Filter Medium | |
|---|---|---|---|---|
| | | | Type 10 | Type 1 |
| | | | Charge Density, $\mu C/m^3$ | |
| 16* | 3550A* | 103 | 1,570 | >-12,200 |
| 18* | 3551A* | 106 | 3,710 | >-9,880 |
| 22* | 3553A* | 562 | 9,390 | >-9,150 |
| 24* | 3554A* | 152 | 6,280 | -8,240 |
| 26* | 3555A* | 65.6 | 6,530 | >-1,040 |
| 2B* | 3428B* | 55.4 | 5,020 | >-1,415 |
| 31* | 3627B* | 67.3 | 738 | >-1,190 |

* Plus 1 ppm Stadis 450

**Table 12– Charging Tendency of Fuels Containing Betz and Stadis 450 on Type 10 and Type 1 Filter Media**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Filter Medium | |
|---|---|---|---|---|
| | | | Type 10 | Type 1 |
| | | | Charge Density, μC/m³ | |
| 17* | 3550B* | 536 | 12,200 | >22,700 |
| 19* | 3551B* | 311 | 16,500 | >24,400 |
| 21* | 3552B* | 409 | 15,500 | >21,400 |
| 23* | 3553B* | 947 | 11,000 | >21,000 |
| 25* | 3554B | 478 | 12,000 | >22,600 |
| 27* | 3555B | 345 | 12,900 | >23,800 |
| 28* | 3116* | 338 | 18,200 | >23,800 |
| 28* | 3116* | 337 | 17,900 | >23,100 |

* Plus 1 ppm Stadis 450

For fuels containing neither Betz nor Stadis, charging was generally higher on the Type 1 medium than on Type 10, but overall, was low on both media (Table 9).

The differences in the charging tendencies on the Type 10 and Type 1 filters is more obvious for fuels containing either Betz or Stadis 450, or both additives (Tables 10-12). Once again, the values for the Type 1 filter are reported as "greater than" since equilibrium was not reached at the end of the run. With the Betz additive (Table 10) and with the combination of Betz and Stadis (Table 12), charging was about twice as high on the Type 1 medium as on the Type 10 reference paper. Fuels containing Stadis 450 alone produced far less charging than fuels containing the Betz additive – see Table 11.

Failure to achieve equilibrium with the Type 1 filter was attributed to the greater density and thickness of this filter vs. the Type 10. The Type 1 filter actually consists of two layers: a solid layer and a fibrous layer. The charging currents obtained on Type 1 filter consisting of two layers are shown in Fig. 20. It is apparent from this figure that equilibrium was not reached at the end of the run when the two layers were used. So the filter was separated into a solid layer and a fibrous layer and the charging tendency test repeated. The results for the individual layers are given in Figs. 21 and 22. These curves indicate that the currents for the solid layer and the fibrous layer are approaching equilibrium at the end of the run. The sum of the currents for the two layers, namely $-2.18 \times 10^{-8}$ (solid layer) and $-1.90 \times 10^{-8}$ (fibrous layer), gives $-4.08 \times 10^{-8}$, which, perhaps, is the equilibrium value of the Full Filter (Fig. 20). Again, the curve for the same fuel on Type 10 filter (Fig. 23) shows that equilibrium was achieved on that filter.

Charging of fuels containing Stadis 450 on the Type 1 filter was erratic (Table 11); some fuels clearly charged higher on the Type 1 filter than on the Type 10, (see Samples 16, 18 and 24 on Table 11) and some charged lower on Type 1, particularly Samples 26 and 28.

Fig. 20-Rising Filter Current Curves for Fuel Sample 21 Using Type 1 Filter (Two Layers)

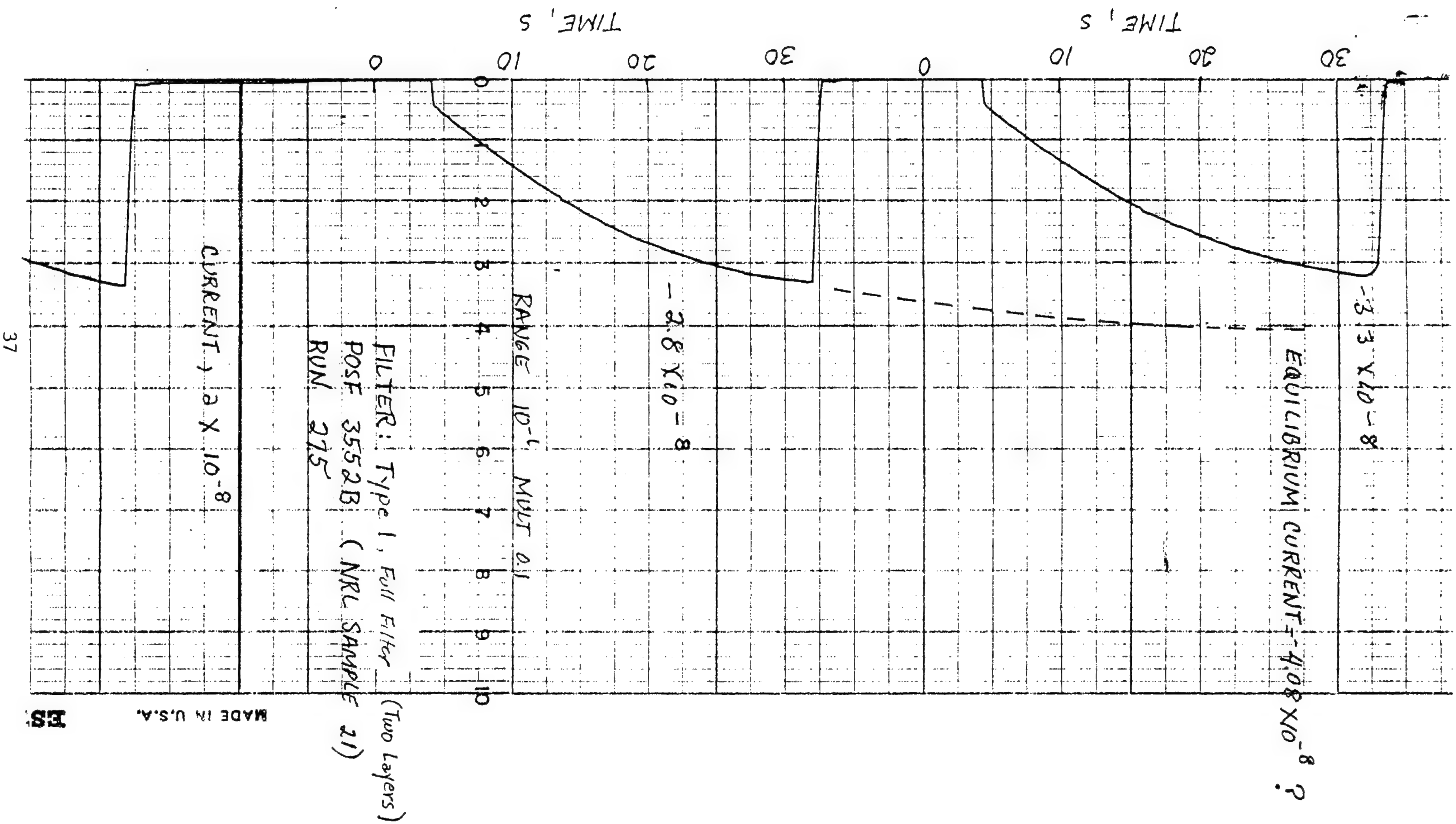


Fig. 21-Rising Filter Current Curves for Fuel Sample 21 Using Type 1 Filter (Solid Layer)

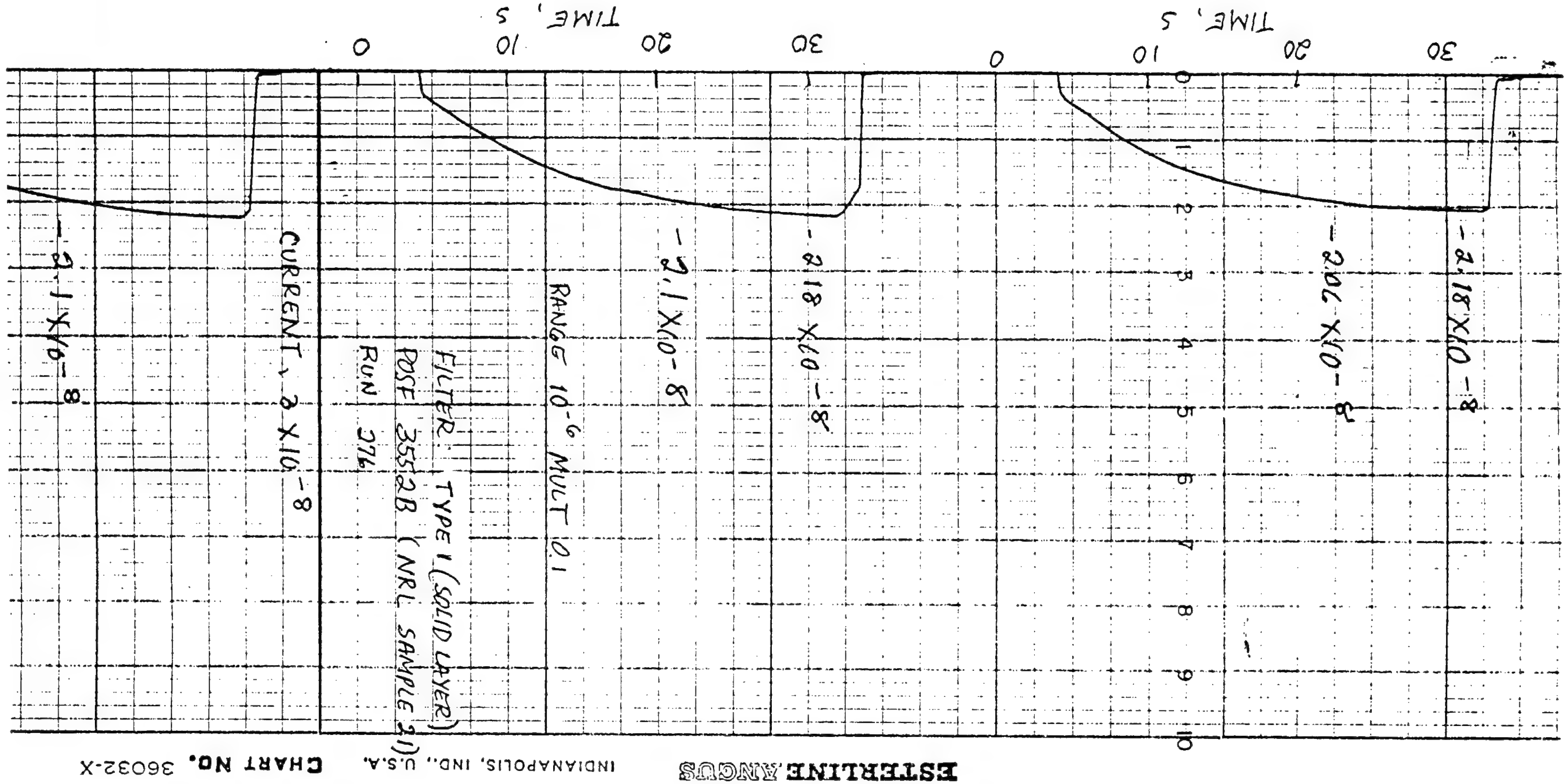


Fig. 22-Filter Current Curves for Fuel Sample 21 Using Type 1 Filter (Fibrous Layer)

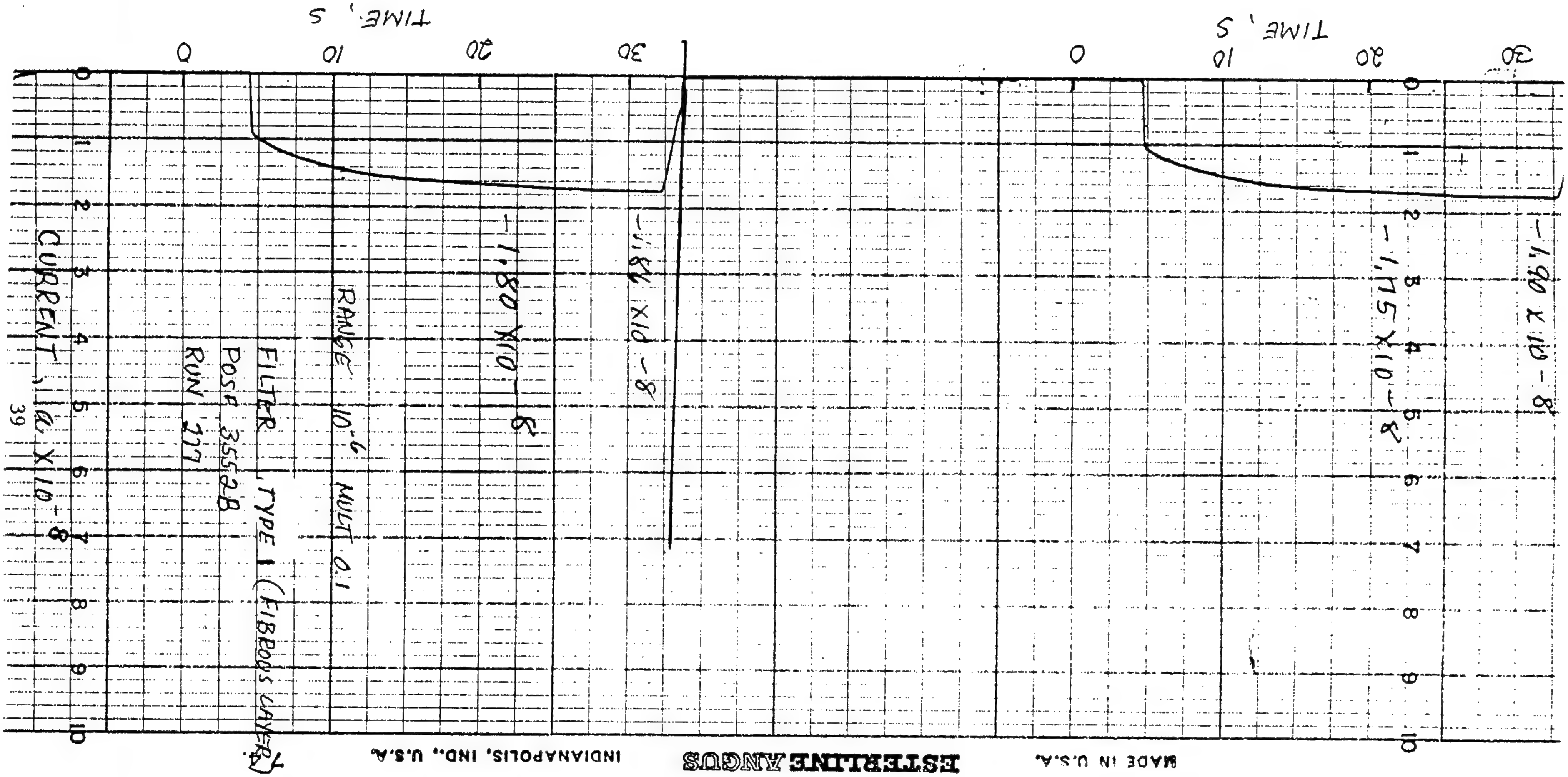
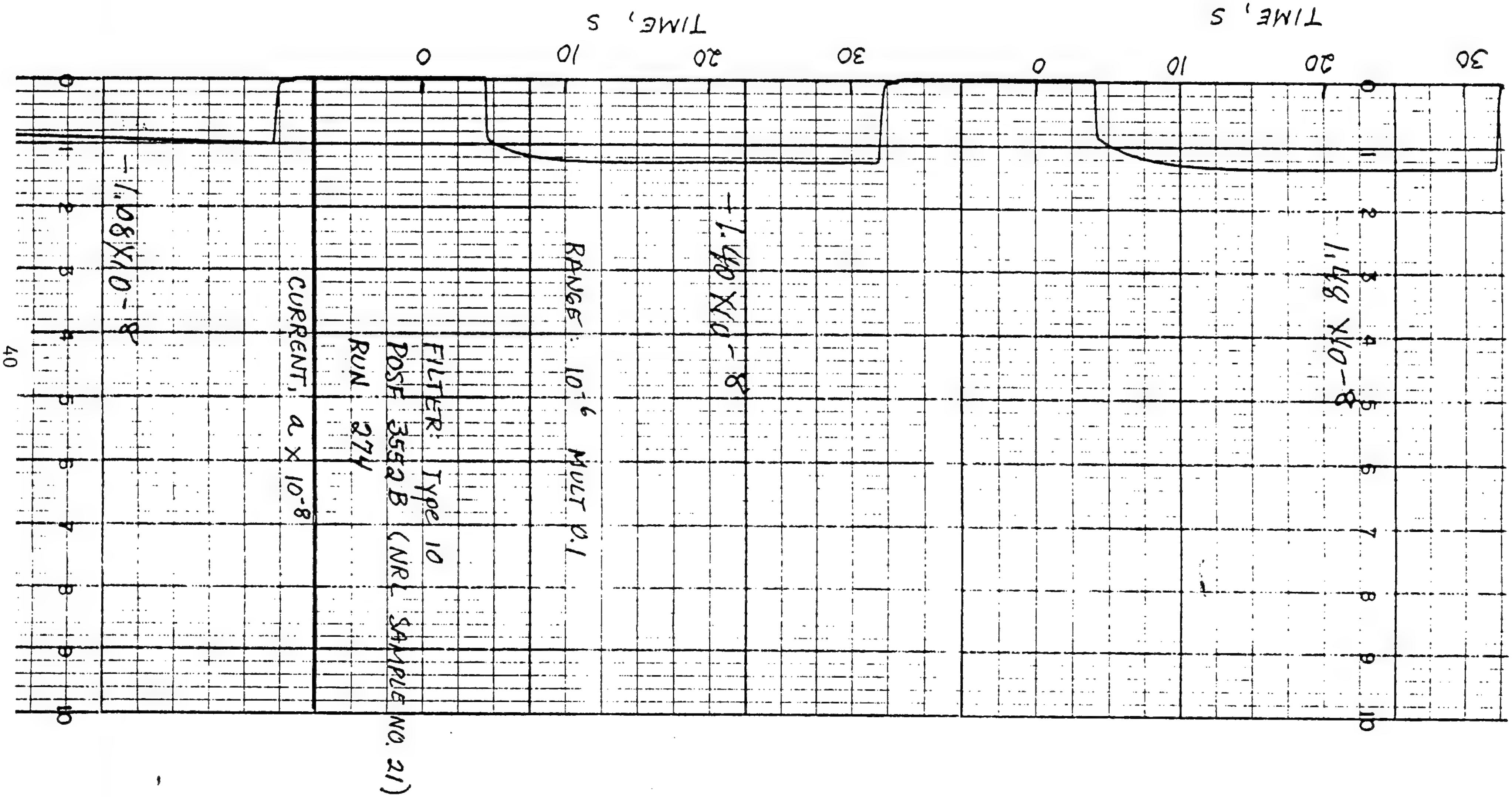


Fig. 23-Filter Current Curves for Fuel Sample 21 Using Type 10 Filter



According to the manufacturer, the Type 1 filter is an experimental material and is not used in any of their current filters.

## Charging on Foam

A comparison was made of the charging tendency of fuels, with and without the Betz or Stadis 450 additives on both the non-conductive, blue foam (10) and on the newer conductive foams (11). The foams and their appropriate Military Specifications are listed in Table 13. The apparatus and procedure were the same as used in an earlier study of electrostatic charging of JP-4 fuel on polyurethane foams (5). The results of these tests as given in Table 14 clearly show that the Betz additive had little effect on charging on either the non-conductive or the conductive foams. Stadis 450, on the other hand, increased the charging tendency on both the non-conductive and conductive foams to approximately 300 $\mu C/m^3$ , which is even higher than the maximum value of 184 $\mu C/m^3$ found earlier for JP-4 fuel containing the static dissipater additive ASA-3 on blue foam (5). High charging on the blue foam is considered to be a potential hazard since the foam is not conductive, and hence can retain a charge. On the other hand, high charging on the conductive foam by a high conductivity fuel would not be considered hazardous since both the fuel and the foam would dissipate the charge rapidly.

**Table 13– Foams Used in Charging Tendency Tests**

| Manufacturer | Conductive Class | Color | Military Specification | Type |
|---|---|---|---|---|
| | | **Non-Conductive Foam** | | |
| Foamex | N/A | Blue | MIL-B-83054 (10) | V (F.P.)* |
| | | **Conductive Foams** | | |
| Crest | II | Charcoal grey | MIL-PRF-87260 (11) | III (F.P.)* |
| Foamex | I | Charcoal grey | MIL-PRF-87260 (11) | VI (F.P.)* |
| Foamex | II | Charcoal grey | MIL-PRF-87260 (11) | VII (F.P.)* |

* F.P. = Fine Pore

**Table 14 – Charging Tendency of Jet A Fuels on Reticulated Foam**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | Foamex Blue | Crest II | Foamex I | Foamex II |
|---|---|---|---|---|---|---|
| | | | Charge Density, $\mu C/m^3$ | | | |
| **A. Samples with No Additives** | | | | | | |
| 43 | 3601A | 0.30 | -24 | -24 | -17 | -66 |
| 45 | 3602A | 0.41 | -4 | -8 | 0 | -92 |
| 41 | 3593A | 2.99 | -32 | -24 | -24 | -89 |
| 26 | 3555A | 3.43 | -29 | -27 | -3 | N/A |
| **B. Samples with Betz Additive** | | | | | | |
| 44 | 3601B | 109 | -58 | -10 | 6 | -26 |
| 46 | 3602B | 121 | -23 | -25 | 10 | -30 |
| 42 | 3593B | 121 | -38 | -13 | -6 | -29 |
| **C. Samples with Stadis 450** | | | | | | |
| 43 | 3601A | 256 | 40 | 40 | 7 | N/A |
| 45 | 3602A | 59 | -254 | -281 | -188 | N/A |
| 41 | 3593A | 90 | -305 | -131 | -65 | -177 |
| 26 | 3555A | 64 | -191 | -122 | -189 | -209 |

## Effect of Storage on Conductivity and Charging Tendency

The effect of storage on conductivity and charging tendency was determined for:

1) Fuels containing neither Betz nor Stadis

2) Fuels containing Betz, but not Stadis

3) Fuels containing Stadis, but not Betz

4) Fuels containing both Betz and Stadis

All fuels contained CI and FSII. The samples were stored in epoxy-lined cans at room temperature for 5-14 months. The results of these determinations are shown in Tables 15-18.

The fuels that contained neither Betz nor Stadis (Table 15) had low initial conductivities and charging tendencies which remained fairly constant in storage for up to 14 months.

**Table 15 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing Neither Betz nor Stadis 450 (Filter: Type 10 Paper)**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | | | Charge Density, $\mu C/m^3$ | | | Storage Time (months) |
|---|---|---|---|---|---|---|---|---|
| | | Initial | After Storage | Δ | Initial | Final | Δ | |
| 2A | 3428 | 0.22 | 0.81 | +0.59 | 480 | 573 | +93 | 14 |
| 18 | 3551A | 2.86 | 6.54 | +3.68 | 1,120 | 628 | -492 | 5 |
| 20 | 3552A | 0.31 | 0.18 | -0.13 | 231 | 310 | +79 | 5 |
| 24 | 3554A | 9.44 | 7.62 | +1.82 | 1,080 | 898 | -182 | 5 |
| 26 | 3555A | 3.43 | 3.43 | 0 | 1,890 | 1,330 | -560 | 5 |

Table 16 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing the Betz Additive, but not Stadis (Filter: Type 10 Paper)

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | | | Charge Density, $\mu C/m^3$ | | | Storage Time (months) |
|---|---|---|---|---|---|---|---|---|
| | | Initial | After Storage | Δ | Initial | After Storage | Δ | |
| **A. Samples in Normal Conductivity Range for Betz Additive** | | | | | | | | |
| 4 | 2926 | 160 | 168 | +8 | 11,500 | 14,600 | +3,100 | 14 |
| 5 | 3055 | 110 | 120 | +10 | 14,500 | 12,900 | -1,600 | 14 |
| 6 | 3119 | 136 | 148 | +12 | 14,400 | 12,000 | -2,400 | 14 |
| 7 | 3116 | 110 | 116 | +6 | 13,600 | 12,200 | -1,600 | 14 |
| 9 | 3284 | 100 | 104 | +4 | 15,100 | 12,400 | -2,700 | 14 |
| 15 | 3480 | 228 | 238 | +10 | 22,600 | 23,900 | +1,300 | 11 |
| 19 | 3551B | 121 | 125 | +4 | 3,210 | 7,750 | +4,540 | 5 |
| 21 | 3552B | 90.5 | 94.5 | +5 | 7,810 | 10,300 | +2,490 | 5 |
| 25 | 3554B | 186 | 195 | +9 | 3,110 | 3,970 | +860 | 5 |
| 27 | 3555B | 132 | 142 | +10 | 1,450 | 1,650 | +200 | 5 |
| **B. High Conductivity Samples*** | | | | | | | | |
| 8 | 3219 | 376 | 426 | +50 | 17,700 | 16,200 | -1,500 | 14 |
| 17 | 3550B | 375 | 384 | +9 | 12,000 | 14,000 | +2,000 | 5 |
| 12 | 3477 | 280 | 188 | -92 | 26,100 | 24,700 | -1,400 | 5 |
| 13 | 3478 | 463 | 385 | -78 | 26,000 | 24,700 | -1,300 | 5 |
| 14 | 3479 | 468 | 283 | -185 | 22,000 | 22,600 | +600 | 5 |

* High conductivity indicates that samples may have contained Stadis 450 in addition to Betz additive, although they were not labeled as such

**Table 17 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing Stadis, but not Betz Additive (Filter: Type 10 Paper)**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | | | Charge Density, $\mu C/m^3$ | | | Storage Time (months) |
|---|---|---|---|---|---|---|---|---|
| | | Initial | Final | Δ | Initial | Final | Δ | |
| **A. Samples in Normal Conductivity Range for Jet A Fuels** | | | | | | | | |
| 18* | 3551A* | 126 | 110 | -16 | 1700 | 5370 | 3670 | 5 |
| 20* | 3552A* | 192 | 138 | -54 | 5280 | 8174 | 2894 | 5 |
| 24* | 3554A* | 189 | 155 | -34 | <519** | 6280 | 5761 | 5 |
| 26* | 3555A* | 108 | 71.2 | -37 | 6100 | 7630 | 1530 | 5 |
| **B. Samples with Initially High Conductivities** | | | | | | | | |
| 16* | 3550A* | 255 | 104 | -151 | 1190 | 793 | -397 | 5 |
| 22* | 3553A* | 611 | 458 | -153 | 4180 | 11,650 | 7470 | 5 |

* Plus 1 ppm Stadis 450

** Charge Density could not be determined since charging current didn't reach equilibrium

**Table 18 – Effect of Storage on Conductivity and Charging Tendency of Fuels Containing Betz and Stadis 450 (Filter: Type 10 Paper)**

| NRL Sample No. | AF POSF No. | Conductivity, pS/m | | | Charge Density, $\mu C/m^3$ | | | Storage Time (months) |
|---|---|---|---|---|---|---|---|---|
| | | Initial | After Storage | Δ | Initial | After Storage | Δ | |
| 17* | 3550B* | 558 | 536 | -22 | 9,760 | 12,200 | +2,440 | 5 |
| 19* | 3551B* | 310 | 311 | +1 | 16,410 | 16,470 | +60 | 5 |
| 21* | 3552B* | 389 | 409 | +20 | 16,600 | 15,500 | -1,100 | 5 |
| 23* | 3553B*3 | 921 | 947 | +26 | 10,200 | 11,000 | +800 | 5 |
| 25* | 3554B* | 451 | 478 | +26 | 10,700 | 12,000 | +1,300 | 5 |
| 27* | 3555B* | 355 | 345 | -10 | 6,770*,** | 12,900 | +6,130 | 5 |
| 7* | 3116*,** | 338 | 337 | -1 | 18,200 | 17,900 | -300 | --- |

* Plus 1 ppm Stadis 450

** Sample 3116 was stored for only 2 weeks

Most of the fuels containing the Betz additive that were in 'normal' conductivity range of 90-228 pS/m didn't change much in conductivity or charging tendency on storage for 5-14 months (Table 16). The exception was Sample 19 which showed a considerable increase in charging tendency, i.e., from 3210-7750 $\mu C/m^3$ after 5 months storage.

Some of the higher conductivity samples, which may have contained Stadis 450 as well as Betz, but were not labeled as such, showed a decrease in conductivity on storage (Samples 12, 13 and 14 on Table 16).

The conductivities of most samples containing Stadis, but not Betz, decreased in storage and their charging tendencies increased, except for Sample 16, which had a decrease in charging tendency (Table 17). Two samples, i.e. Samples 22 and 24, had increases of over 5000 $\mu C/m^3$. Although one sample exceeded 10,000 $\mu C/m^3$, in general, the charging tendencies for individual samples containing the Stadis 450 additive were lower than for the same samples containing the Betz additive. However, fuels varied widely in their responses to both additives.

The conductivities of all samples containing both Betz and Stadis did not change significantly in storage (Table 18). However, the charging tendencies of two samples, i.e., Samples 17 and 27, increased considerably in storage. Such changes, together with the observation the fuels vary widely in their responses to both additives, are indicative of the complex interactions that occur between the additives and chance impurities in fuels.

## SUMMARY AND CONCLUSIONS

For fuels in the normal conductivity range of Jet A (0.1 – 10 pS/m), the Betz additive increased the conductivity of all but one sample to above 100 pS/m; for 15% of the samples, the conductivity was over 150 pS/m which is the lower specification limit for JP-8 fuels (7).

Stadis 450, at a concentration of 1 ppm, increased the conductivity of fuels not containing the Betz additive, on average, 138 pS/m: in fuels containing the Betz additive, the average increase was 252 pS/m.

The results of the charging tendency measurements for fuels on all of the filter media and reticulated foams tested are summarized in Table 19. As indicated in the table, Jet A fuels not containing the Betz or Stadis 450 additives exhibited low charging on all media, including the Type 10 reference filter.

Fuels containing the Betz additive gave low charging on all media except the Type 10 reference filter and a coalescer medium designated as Type 1. In some fuels, the charge densities for the Betz additive on the Type 10 filter equaled the highest levels attained in previous studies of additives, i.e., above 20,000 $\mu C/m^3$. Even higher charging was found on the Type 1 filter. However, such high charging is of little concern from the standpoint of electrostatic hazards under <u>most</u> circumstances since the conductivities of the fuels are so high, i.e. above 90 pS/m.

**Table 19– Summary of Charging Tendency Data**

| Type of Medium | No Additive | With Betz | With Stadis 450 |
|---|---|---|---|
| Coalescer, Excluding Type 1 | Low | Low | High on fiberglass, felt, polyester and prefilter media |
| | | | |
| Type 1 Coalescer | Low | Very High* | Usually high, but not always |
| | | | |
| Separator, Excluding Type 10 | Low | Low | Low |
| | | | |
| Type 10 Separator | Low | Very High* | Low |
| | | | |
| Monitor Cartridge | Low | Low | High on media paper and on superabsorbent and absorbent media |
| | | | |
| Foamex, Blue, Non-Conductive Foam | Low | Low | High** |
| | | | |
| Crest, Conductive Foam Class II | Low | Low | High** |
| Foamex, Conductive Foam Class I | Low | Low | High** |
| Foamex, Conductive Foam Class II | Low | Low | High** |

* Usually >10,000 $\mu C/m^3$

** In the range of 100-300 $\mu C/m^3$, which is high charging on a foam

The high conductivity would permit most of the charge to dissipate in less than 1 second after it is generated. The possible exceptions where a hazard might exist despite the high conductivity of the fuel are: during the filling of an empty filter vessel or when the fuel flows over a low conductivity reticulated foam.

The charging tendencies of fuels containing the Betz additive varied widely. However, for a given fuel, the charging tendency increased steadily with increasing conductivity reaching a maximum in the range of 150-250 pS/m and then decreasing at higher conductivity levels. However, the high charging of fuels containing the Betz additive on the Type I experimental coalescer medium indicates the need for electrostatic testing of any new filter medium intended for use with JP-8 + 100 fuels.

Fuels containing Stadis 450 exhibited high charging on most coalescer media, particularly fiberglass and felt, and on the media paper and superabsorbent and absorbent media

from the monitor cartridge. They also gave high charging on both the conductive and non-conductive foams, but not on the separator media or on the Type 10 reference filter. It should be emphasized that all of the filter media tested were designed for use with the Betz additive and may or may not be representative of the media being used with fuels containing Stadis 450 today.

Finally, in response to the original objective of this study, it was concluded that:

1) The Betz additive does not increase the electrical conductivity of all Jet A fuels above the current JP-8 specification minimum of 150 pS/m. Hence, the Betz additive does not obviate the need for a static dissipater additive in JP-8 fuels.

2) The Betz additive produced exceptionally high electrostatic charging on only two filter media, neither of which is currently being used with JP-8 fuels. Charging on all of the other 37 media tested was quite low for fuels containing the Betz additive.

## REFERENCES


(1) Standard Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter, Designation: D4308-95. American Society for Testing and Materials, Philadelphia, PA, February 15, 1995.

(2) Matulevicius, E., "Mini-Static Test Procedure," Exxon Research and Engineering Co., Linden, NJ, June 19, 1989.

(3) "A Survey of Electrical Conductivity and Charging Tendency Characteristics of Aircraft Turbine Fuels," CRC Report 478, Coordinating Research Council, Atlanta, GA, April, 1975.

(4) Leonard, J.T. and Bogardus, H.F., "Pro-Static Agents in Jet Fuels," Naval Research Laboratory Report 8021, August 16, 1976.

(5) Leonard, J.T. and Affens, W.A., "Electrostatic Charging of JP-4 Fuel on Polyurethane Foams", Naval Research Laboratory Report 8204, March 3, 1978.

(6) Standard Specification for Aviation Turbine Fuels, ASTM Designation D1655-96C, American Society for Testing and Materials, Philadelphia, PA.

(7) Military Specification: Turbine Fuel, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-45. MIL-T-83133D, Amendment 1, 19 September 1995.

(8) Leonard, J.T. and Carhart, H.W., "Effect of a Static Dissipater Additive on the Charging Tendency of Jet Fuels," Naval Research Laboratory Report 6952, November 12, 1969.

(9) Leonard, J.T. and Carhart, H.W., "Effect of Navy Special Fuel 0.1 on the Charging Tendency of Jet Fuel," Naval Research Laboratory Report 6953, November 20, 1969.

(10) Military Specification MIL-B-83054A (USAF), 15 August 1973, Baffle Material, Aircraft Fuel Tank.

(11) Performance Specification MIL-PRP-87260A (USASF), Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks, 7 February 1992.